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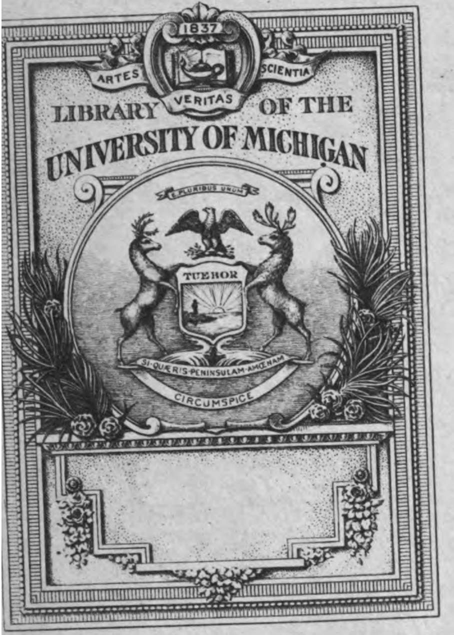
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THE

SUBJECT MATTER

OF A

COURSE OF SIX LECTURES

ON THE

NON-METALLIC ELEMENTS.

BY

PROFESSOR FARADAY.

DELIVERED BEFORE THE MEMBERS OF THE ROYAL INSTITUTION,
IN THE SPRING AND SUMMER OF 1852.

ARRANGED, BY PERMISSION, FROM THE LECTURER'S NOTES, LENT FOR THE OCCASION

BY

J. SCOFFERN, M.B.,

Late Professor of Chemistry at the Aldersgate College of Medicine

TO WHICH IS APPENDED,

REMARKS ON THE QUALITY AND TENDENCIES OF CHEMICAL PHILOSOPHY, ON
ALLOTROPISM, AND OZONE; TOGETHER WITH MANIPULATIVE DETAILS
RELATING TO THE PERFORMANCE OF EXPERIMENTS
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WILLIAM THOMAS BRANDE, ESQ.

OF THE ROYAL MINT,

F.R.S., M.R.I., &c. &c.

Professor of Chemistry at the Royal Institution,

THE FOLLOWING PAGES ARE INSCRIBED, AS A SLIGHT MARK
OF RESPECT AND ESTEEM,

BY

J. SCOFFERN.

Professor Brande's Lectures on the application of Organic Chemistry to the Industrial Arts, are in course of reproduction from his Lecturing Notes, and, with his sanction, they will shortly appear.

PREFACE.

Had this volume consisted of Professor Faraday's Lectures alone, it might have gone into the literary world without further preface than such as is conveyed in the intimation of its appearance with the fullest sanction and consent of the lecturer. An explanation, however, is rendered necessary, when, as in the present case, an editor intersperses additions of his own.

It may suffice on this topic to state that the extraneous portions of the volume suggested themselves during an interview with Professor Faraday, in the course of which the process of rendering an oral discourse into a literary shape formed the topic of conversation. It was conceded that lectures, for the most part, have reference to others already delivered; that a lecturer frequently indicated collateral facts merely; not demonstrating the line of evidence by which these facts had been arrived at—because so far as might relate to a particular audience the knowledge of such facts was assumed. It was conceded, moreover, that a chemical lecturer, more perhaps than any other, possessed a means of demonstrating facts not available to the essayist—*the demonstration of experiment*—that mute eloquence of action which silently compresses whole pages of written lore into one short act of manipulation, and renders verbal explanation unnecessary.

These and many other special peculiarities, in which the functions of a lecturer differed from those of an author, having been discussed—it was conceded that a mere verbatim report of an experimental course of lectures, would by no means render, under a literary aspect, the spirit in which these lectures were delivered.

Accordingly—being anxious to obtain these lectures for a public journal, it appeared that the object would be most efficiently secured by attending them regularly—embracing their scope, noting their experiments, striving to imbibe their philosophy—and transferring their language to paper, whenever language, not experiment, might be the form adopted for expressing a sentiment, or inculcating a truth.

This plan was adopted accordingly: and to render it still more perfect, Professor Faraday kindly and cordially furnished, immediately on the conclusion of each discourse, his lecturing notes: moreover, whenever any difficulty occurred, he no less kindly lent the aid of his supervision. Originally intended for the pages of a journal, the rendering of Professor Faraday's lectures was necessarily much condensed; when therefore public appreciation had made a fuller expansion of them desirable, the lecturing notes of Professor Faraday proved of redoubled utility; containing, as they did, various memoranda of points indicated for discussion, but not touched upon during the lecture for want of the necessary time. These dormant notes I have frequently taken the liberty to expand.

Enough will have been stated to make known the warrantry under which I have acted in rendering the lectures themselves; and it equally applies as accounting for the existence of those parts of the volume which are my own: parts which are merely to be considered as very unworthily taking the place of other sources o information with which Professor Faraday assumed his audience to be acquainted, and to portions o which he referred.

In conclusion, I have now to add, that although the contents of the following pages will be recognised by those who had the gratification of listening to the original lectures, as in spirit always, in language frequently—similar to their oral prototypes: yet, in deference to the wishes of the lecturer, it remains for me to state that the present volume is to be considered the result of an appreciation by others rather than himself of the merits of the lectures embodied in this course.

CHEMISTRY OF THE NON-METALLIC ELEMENTS.

◆

GENERAL INTRODUCTION.

I.

THE QUALITY AND TENDENCIES OF CHEMICAL PHILOSOPHY —FIRST CHEMICAL EPOCH—ALCHEMY—BELIEF IN OCCULT AGENCIES—PARACELSUS—THE INFLUENCE OF HIS CHARACTER AND WRITINGS.

WHILST it is the peculiar attribute of astronomy to awaken our minds to an appreciation of those stupendous orbs which revolve in space, to waft us ideally into those far-off regions where the bright luminary of our system would pale into the feeble twinkling of some distant star, and this turbulent world of ours, if not lost altogether to our gaze, would fade into the misty streak of some faint galaxy—it is an attribute of chemistry to raise up within us sentiments of another kind.

Less stupendous in its first aspect than astronomy though it be, the science which teaches us to contemplate the immensity of space, and the grandeur of its orbs; less tangible than astronomy in its first manifestations—chemistry, nevertheless, by the wonderful metamorphoses which it discloses, by the protean display of physical changes which it brings before our eyes, by the demonstration it affords of the indestructibility of matter under the agency of existing laws, is perhaps more calculated than any other science to awaken within us the most ennobling sentiment the mind can contemplate—the sentiment of immortality. If the grosser parts of our earth and its inhabitants pass thus undestroyed through all the vicissitudes of death, fire, and decay, how impossible is it to assume a destruction of a spiritual essence! Totally irreconcilable with the genius of chemical science is the idea of destruction.

Chemistry is essentially a science of experiment;—most of the conditions under which its phenomena are developed requiring the disposing agency of man: yet there occur naturally a sufficient number of chemical phenomena to rivet the attention of a reflective mind, and lead it to some acquaintance with that mutation of form apart from destruction which is so striking an attribute of chemistry.

Many a reflective sage must have speculated ere now during the very infancy of the world, and long before chemistry had invoked the aid of experiment, on the cause and consequence of such ever-recurring phenomena as combustion and evaporation. The circumstance must have been noticed that the waters of lakes and streams, although exhausted in vapour by the agency of the sun's rays, and dispersed, were not dispersed to be destroyed; but that, entering into clouds, the aqueous vapours remained hovering above until the operation of some natural cause should effect their descent to earth once more in hail or snow, dew or rain. Many a reflective sage in ancient times must have speculated on the results of combustion; more subtle, less amenable to scrutiny than those of evaporation though they be; and although neither the priests of Isis nor the sages of Greece knew the means of collecting, as does the chemist of our own times, the fleeting gaseous elements which are scattered by combustion, yet the spiritual intuition of these philosophers anticipated in a poetic myth the slower evidence of induction. In the fabled rising of the Phœnix from her ashes is displayed a credence in the non-destructibility of matter under the operation of existing laws; and the many changing aspects of Proteus seem but the expression of a belief in the occurrence of chemical transformations.

No sooner were the manifestations of chemical action displayed by experiment, than the wonderful mutations of form as evidenced by combination and decomposition gave rise to hopes that the baser metals might be transmuted into gold; a credence which, when we come to investigate the period of its first origin, carries us back into the furthest recesses of antiquity.

Viewed under the aspect of a prevailing chemical furor, the belief in alchemy may be said to belong to the middle ages; but amongst all its votaries a sort of universal credence was given to the remote origin of the doctrine. The Egyptian Hermes* was held to be the accredited originator of alchemy, and the notion of the possibility of transmuting base metals into gold has been thought by some writers to have existed amongst the Greeks at a period coeval with the Argonautic voyage in quest of the Golden Fleece. Suidas, in his lexicon published during the 11th century, expressly states under the head "Δερας," that the golden fleece was only a mythical expression for a parchment document on which had been written a description of the process for making gold.

Without minutely discussing the opinions or the history of alchemical writers, it may suffice to remark that a belief in the possibility of making gold, and extending the duration of man's corporeal life, constituted the foundation of alchemy. Not that these tenets were received by all professing alchemy to the same extent; in this respect the greatest difference of opinion obtained. Some votaries merely contented themselves by expressing their belief in the possibility of transmuting the base metals into gold, whilst others proclaimed to the world in mystic terms their possession of the secret.

Rescued from the obscure jargon of the language in which these descriptions were veiled, the opinions of the alchemists as relates to the composition of metals, were far from irrational,—always remembering the kind and the amount of information at their disposal. All the metals, they believed to be compounds:—the baser metals containing the same elements as gold, from which they differed on account of their association with impurities. These impurities being separated, it was imagined that gold would remain. The agent supposed to be capable of effecting this purification was the philosopher's stone, which, although many alchemists did not hesitate to state they had made, the greater number limited themselves to the expression of a belief in its existence.

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* Hermes Trismegistus.

It would be ungrateful in the chemical philosopher of the present day to contemn utterly the striving of the alchemists. Many of these enthusiasts there were who shadowed forth in their hyperbolic phrases the sterner facts of induction; and even the labours of that sordid class who had no nobler aim in view than the amassing of wealth, disclosed a vast store of collateral facts for the benefit of future chemistry. Nor is it, perhaps, just to stigmatise by so harsh a term as insanity that belief in an elixir which should be capable of extending the life of man, in his corporeal form, beyond the limits allotted to mortality. Having started from the basis of considering gold a noble metal, untarnishable in the air, imperishable in the fire, unalterable by all common solvents, it does not seem a flight of imagination beyond the confines of sanity, although fanciful, to assume that the human frame might be so imbued with gold as to be proof against many of the destructive agencies to which it is ordinarily subjected. Many a recent medical hypothesis has rested on a basis far less seemingly rational than this.

The hope expressed by many alchemists of their being enabled to extend the life of man beyond that of the patriarchs—nay, even to render him immortal in his corporeal form—was a wild flight of fancy starting from a basis of seeming probability; a pushing to extremes of a theory in itself not so much at variance with given premises as many have conceived. Doctrines in themselves rational are often strained by ardent minds until they assume the semblance of error,—theories often forced beyond their proper sphere,—until, breaking loose from restraint, they lead where they ought to follow, suggesting accordances rather than associating facts. Such tendencies are common to all doctrines in all times. It is a quality of the human mind to be ever striving at perfection, ever aiming at the acquisition of that which seems to be true. The isolated fragments of truth which lie scattered in our path, we are ever endeavouring to bring together or arrange. Too confident in the strength of our own perceptions—too oblivious of the narrow limits which restrain the excursions of our reasoning, we are ever prone to set in order, and construct into a fondly-thought temple of perfection, those scattered fragments of truth. The temple stands approved by our own complacent scrutiny, —we die, and others fill our place. Then comes the inductive reasoning of a future age, and proves the cherished edifice of truths so pleasing to our eye, to be a monstrous distortion.

During the period of a century or more, it was the custom to spurn the doctrines of the alchemists; not only in the literal acceptation of these doctrines, but even as semblances of philosophic truths. The time has passed for this opinion to be maintained. Within the last few years a series of manifestations has been noticed which goes far to vindicate many opinions of the alchemists. The condition of *allotropism*, or the quality which certain bodies possess of assuming two marked phases of chemical and physical existence, shatters the opinion on which our absolute repudiation of the doctrine of transmutation was based. Chemists now regard the idea of transmutation, not so much in the sense of being absolutely, essentially false, as a vision of truth distorted by the aberration of the medium through which it has been made to pass. Although a belief in the existence of an universal elixir and the philosopher's stone was not extinct even so late as the beginning of the present century,* yet the decadence of alchemy as a popular hallucination, may be said to date from the time of Paracelsus. He, in despite of his wild fanaticism, had the merit of strengthening the alliance between chemistry and medicine, by rendering the public familiar with the exhibition of certain medicinal preparations, and of contributing to the facts of chemistry by many original discoveries.

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* I allude to Peter Woulfe, who died in the year 1805, of whom remarks Professor Brande (Manual of Chemistry), "it is " to be regretted that no biographical memoir has been pre- " served. I have picked up a few anecdotes respecting him from " two or three friends who were his acquaintances. He occupied

The life and writings of Paracelsus seem naturally

" chambers in Barnard's Inn while residing in London, and " usually spent the summer in Paris. His rooms, which were " extensive, were so filled with furnaces and apparatus that it " was difficult to reach his fireside. Dr. Babington told me " that he once put down his hat, and never could find it again, " such was the confusion of boxes, packages, and parcels that " lay about the chamber. His breakfast hour was four in the " morning; a few of his select friends were occasionally invited " to this repast, to whom a secret signal was given by which " they gained entrance, knocking a certain number of times at " the inner door of his apartment. He had long vainly searched for " the elixir, and attributed his repeated failures to the want of " due preparation by pious and charitable acts. I understand " that some of his apparatus are still extant, upon which are supplications for success, and for the welfare of the adepts. Whenever he wished to break an acquaintance, or felt himself " offended, he resented the supposed injuries by sending a present " to the offender, and never seeing him afterwards. These " presents were sometimes of a curious description, and consisted " usually of some expensive chemical product or preparation. " He had an heroic remedy for illness; when he felt himself " seriously indisposed, he took a place in the Edinburgh mail, " and, having reached that city, immediately came back in the " returning coach to London. A cold, taken on one of these " expeditions, terminated in an inflammation of the lungs, of " which he died in 1805."

to indicate the point of immergence of the first chemical epoch into the second. Before the time of this wild enthusiast, it had been the universal custom to refer unknown agencies to the operation of supernatural causes, a custom which, however much it may have been conducive to the free play of poetic imagination, is but little accordant with the genius of inductive philosophy. With Paracelsus this universal belief in occult agencies may be said to have ceased; and, as the expiring flame burns sometimes brighter before its final extinction, so did the belief in occult causes, before its final extinction, become intensified in the mind of Paracelsus. He was, perhaps, the most universal Pantheist the world had seen. Every existing thing, however seemingly inanimate, was invested by Paracelsus with an ideal life, and was assumed to perform its vital functions under the guidance and direction of some familiar spirit. The popular names of many chemical substances at this day bear ample testimony to the general credence which must have prevailed in the early days of chemical, or more properly speaking, alchemical philosophy. The words *spirit of wine*, *spirit of salt*, *spirit of nitre*, and so forth, sufficiently bespeak a general belief formerly existing in respect of supernatural or occult agencies.

"Paracelsus," remarks an able French author, "may be regarded from many points of view; but the one which will interest us most relates to the impulsion, the new direction which he imparted to chemistry; and although it would be difficult to collate the views of that singular individual into an ordinary scheme, yet I cannot help referring to him as the originator of various theories.

At the commencement of the sixteenth century, demonology and the cabalistic art pre-occupied the minds of all. In vain had astrology been proscribed by a Papal bull and by the faculty of Paris; in vain had alchemy been interdicted by the Senate of Venice; the pretended sciences still continued to be taught in the majority of Schools. Men of true science did not scruple to become their advocates. George Agricola, Jean Bodin, Jerome Carden, Thomas Erastes, were amongst its most strenuous advocates. Felix Plater, Ambrose Paré, nay, even the judicious Femel, did not hesitate to lend it their faith. During the same century, the plague and other epidemics broke out; to remedy them, the populace had, first of all, recourse to astrology and cabalistic practices; then they tried the manifold pharmacy of the Arabians, which, failing in its turn, recourse was at last made to alchemy, which offered a host of new remedies, some of them not devoid of efficaciousness.

In this condition was the popular mind when Paracelsus presented himself as the instigator of a radical reform in medical doctrine; but his audacity, his disdain, his violent attacks against admitted opinions, although unanswered, did not even suffice. He therefore invented new doctrines—doctrines which, he said, would overthrow all that had gone before. He commenced by emitting a sort of physiological theory, founded upon the application of astrology to the functions of the human body. He regarded magic as the culminating point of all science, and he believed its study to be a matter of prime importance to all destined for the medical profession. Finally, he went the length of affirming that, by means of the cabalistic art and chemistry, health might be re-established, life might be extended, and that even animated beings, *homunculi*, might be produced.

As regards the intro-chemical doctrine, of which he must be regarded the founder and the chief, it reduces itself into this proposition; that the composition of the body of man being formed by the union of a *sidereal* (that is to say, immaterial) salt, a sulphur, and a mercury, and diseases being caused by the alteration of this compound, they could only be combated by chemical means, combined with astral influences.

With the view of explaining the action of medicaments, he substituted for the elementary qualities of Galen, a reasoning being—the *archæus*, which seemed to discharge the part of nature in the play of our organs; which combined elements, elected the materials of nutrition, ejected impurities, and re-established the equilibrium of physiological functions. The archæus was, in the doctrine of Paracelsus, the spirit of life, the sidereal portion of man's body; hence, we may regard it as pretty nearly identical with the vital principle of the moderns. Having adopted the system of Genii, Paracelsus attached to each natural object its own familiar spirit, to which he gave the name of *Olympian* spirit. Hence arose the supposed relation between man and various natural objects; and this belief, so long admitted, it was that attributed to certain substances qualities having reference to their natural forms. It will be evident that Paracelsus was the originator of dogmatic chemistry. From this moment henceforth, a strong line of demarcation was drawn between chemists and alchemists. The latter continued their vain researches, whilst the former pursued the application of positive facts to medicine and the industrial arts.

Notwithstanding all that was vague, and singular in his ideas, it cannot be denied that Paracelsus advanced science by his own researches, and by the discovery of many facts. It was he who first offered a true chemical and medical view of the preparations of antimony, mercury, and iron. He was the first to promulgate the doctrine that certain poisons, when taken in fitting doses, act as safe and efficient medicines. He was the first to recommend the employment of preparations of lead in diseases of the skin. In like manner he employed copper, nay, even arsenic, as external applications for effecting cauterization. He employed sulphuric acid in diseases resulting from poisoning by lead, a mode of treatment which has remained in vogue up to the present day. He was the first to distinguish alum from copperas, remarking that the former contained an earth, the latter a metal. He was the first who mentioned zinc, regarding this metal, it is true, as a modification of mercury and bismuth. He admitted the existence of other elastic fluids besides atmospheric air, specially alluding to hydrochloric acid gas, and sulphurous acid gas, both of which, however, he regarded as forms of water and of fire. According to him, the spark of flint and steel was the product of fire contained in the air. He was the first to point out, that when oil of vitriol was made to act upon a metal, air was disengaged, which air was *one of the elements of water*. He was aware that the presence of air was indispensable to the respiration of animals, and the combustion of wood. He stated that calcination *killed* those metals subjected to it, and that *charcoal reduced or revived* them. "There exists a certain thing," said he, "which we do not perceive, and, in the midst of which is plunged the whole universe of living beings. This thing comes from the stars, and we may obtain a notion of it in the following manner:—Fire, in order that it may burn, requires wood, but it also requires air. The air, then, is the life, for, if air be wanting, all living beings would be suffocated, and die." In another part of his writings, Paracelsus states that digestion is a solution of aliments, and that putrefaction is a transformation: that, moreover, everything dies previous to resuscitation in some other shape. These great chemical and physiological views—this generalization of the phenomena of combustion and respiration—prove that, despite his drunken hallucinations, Paracelsus held within him a spirit of deep penetration.

II.

SECOND CHEMICAL EPOCH—DOCTRINE OF OCCULT CAUSES YIELDS TO THE DOCTRINE OF PHYSICAL FORCES—CHEMISTRY ASSUMES THE CONDITION OF AN INDUCTIVE SCIENCE—THE PHLOGISTIC THEORY AND ITS OVERTHROW.

A NEW chemical era may be said to have dawned with Van Helmont, the successor of Paracelsus, who, although somewhat tinctured with the doctrines of his master, repudiated, nevertheless, that universal pantheism and belief in occult causes which constituted so prominent a quality in the writings of Paracelsus. It was Van Helmont who first discriminated between various aëreal substances, and who, for the sake of precision, first employed the term "gas" to designate all fluids permanently aëreal under common temperatures and pressures, not being atmospheric air. Like Paracelsus, Van Helmont believed in the existence of the Archæus, a spirit or dæmon, whose duty it was to superintend the functions of animal digestion and secretion. In other matters, too, he was deeply tinctured with spiritualism,—but the introduction by him of a term to individualise aërial fluids—bodies which, so far as he knew, were devoid of weight, cannot be regarded otherwise than an indication of the progress of inductive reasoning. Contemporary with Van Helmont was Galileo, to whom Physics, if not Chemistry, owes so much; and after Galileo came Torricelli, to whom Pneumatic Chemistry is so deeply indebted. The celebrated explanation of the reason why water rises in the barrel of a suction pump—the action being referred to atmospheric pressure—affords a striking commentary on the downfall of the general belief in occult causes. Henceforward, philosophers, instead of referring to the agency of spirits and genii every phenomenon which might not admit of a physical explanation, began to speak of the operation of laws,—a term not involving any theory, but merely expressing an ultimate fact.

As the recognition of the physical nature of aëreal fluids and a discrimination between gaseous bodies first dates from the period of Van Helmont and Galileo, —whose speculations led the way to pneumatic investigations by Torricelli,—so, the discovery of the air-pump by Otto Guericke advanced, by another step, the science of pneumatic chemistry, created an area for the master researches of Hooke and Boyle, and led to that crowning manipulative discovery of Priestley, the pneumatic *trough*, an instrument which has been of such inestimable advantage in promoting the advance of chemistry.

Hitherto, the explanation of chemical phenomena had not been aided by the adoption of any consistent theory, sufficiently large to comprehend the facts already determined, or sufficiently expansive to embrace such future exigencies as might arise. Such a theory, however, was initiated about the middle of the seventeenth century by Beccher,[*] and received almost universal acceptation before the end of that century by Stahl;[†] accordingly, it is generally known as the phlogistic theory of Beccher and Stahl. This theory proved competent to afford a rational explanation of most chemical phenomena;—not only those of ponderable bodies, but such also in which the imponderable agents were concerned.

The *phlogistic theory* of Beccher and Stahl set out with begging the postulate of the existence of a substance or agency denominated *phlogiston,* which, although never obtained in a state of isolation, was believed to possess the characters of an earth, and to have the quality of converting or tending to convert everything with which it might combine into an earth, or something resembling that form of matter. Directly or indirectly, this phenomenon was assumed to be concerned in the production of every chemical phenomenon. but the most marked instances of its operation were to be recognised in the phenomena of combustion. If phosphorus be burned in oxygen gas, the phosphorus is converted into a white smoke greedily attractive of water. If it be dissolved in water, and the water evaporated, a vitreous-looking solid (*phosphoric acid*) remains. If this result be mixed with charcoal, and distilled, phosphorus in its original state comes over. Hence it was inferred by Beccher and Stahl, that the phosphorus, by combustion, had lost something—*the imaginary phlogiston*, and that charcoal, under the agency of heat, gave this phlogiston back. Instead of phosphorus, several metals may be substituted in exemplifying the preceding doctrine. Lead, for instance, if exposed at a red heat to the action of atmospheric air, becomes converted into *red lead*—or, according to the nomenclature of Beccher and Stahl, *calx of lead*, because of its assumed loss of phlogiston; and if this red lead or calx be heated with charcoal, pit coal, or almost any ordinary combustible, lead once more results. It cannot be denied, therefore, that the antiphlogistic theory was both ingenious and specious: competent to explain rationally a large range of chemical phenomena, and in direct variance with none.

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[*] Born 1625—died 1685.

[†] Born 1660—died 1685.

This theory maintained an undivided sway until after the discovery of oxygen, when it was speedily proved by Lavoisier that the results of combustion are heavier than the substances burned—heavier by the exact weight of that oxygen which enters into combination with them; and which assumes the state of carbonic acid, by union with carbon, when the calx or oxide is exposed in contact with charcoal to a sufficiently high temperature.

It is not a little extraordinary that Beccher and Stahl were both aware that the calces of metals are heavier than the metals which yield them, yet this knowledge did not shake their belief in the phlogistic theory. The illustrious Boyle, who does not seem to have been aware of the doctrine of Beccher and Stahl, although it was promulgated before his death, performed a very remarkable experiment, which, had he subjected to mature reflection, might have led to the discovery of oxygen gas, and to an overthrow of the phlogistic theory. Having fused some tin in an open glass vessel, and retained it for some time at the melting temperature, he allowed it to cool, and weighed the result, which was now found to be heavier than the original tin. This experiment is merely cited by Boyle with the view of proving the materiality of heat, and, as interpreted by him, is, in so far, inconsistent with the phlogistic theory, that, according to Boyle, the calx or oxide of tin was not tin *minus* something, *i. e.*, the imaginary phlogiston, but *plus* something,—*i. e.*, heat, or the matter of heat. *

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* In reference to this experiment of Boyle, Professor Johnstone has made the following pertinent remark :—" How much the progress of science depends on the mode in which phenomena are interpreted by the first observers, is strikingly illustrated in the case of certain experiments of Robert Boyle. He observed that, when copper, lead, iron, and tin, were heated to redness in the air, a portion of calx was formed, and there was a constant and decided increase of weight (*Experiments to make fire and flame ponderable.* London, 1673). This experiment he repeated with lead and tin in glass vessels, hermetically sealed, and found still an increase of weight; but observed further, that when the '*sealed neck of the retort was broken off, the external air rushed in with a noise*' (*Additional experiments, No. V., and a discovery of the perviousness of glass*

Very soon after the time of Stahl, the gain of weight acquired by substances after combustion had become a phenomenon so generally known, that such as advocated the phlogistic theory were obliged to devise some other explanation for the phenomenon. Accordingly, the hypothesis was assumed, that phlogiston, in itself, possessed the quality of levity; hence, that its presence must confer the property of lightness; indeed, the phlogistic theory was held with extraordinary pertinacity, until the discovery of oxygen by Priestley rendered its further acceptation untenable.

In the year 1774, Dr. Priestley, being at Paris, demonstrated to Lavoisier that oxygen gas could be extracted from red oxide of mercury, a demonstration which caused Lavoisier to become a powerful advocate

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to ponderable parts of flame,—Exp. iii.). From this he reasoned correctly, that in calcination, the metal lost nothing by drying up, as was generally supposed, or that if it did, 'by this operation it gained more weight than it lost.'—Coroll. ii. But this increase of weight he attributed to the fixation of heat, stating it as 'plain that igneous particles were trajected through the glass,' and that 'enough of them to be manifestly ponderable did permanently adhere.' Had he weighed the sealed retort before he broke it open, he must have concluded that the metal had increased in weight at the expense of the enclosed air. He stood, in fact, at the very brink of the pneumatic chemistry of Priestley; he had in his hand the key to the great discovery of Lavoisier. How nearly were those philosophers anticipated by a whole century, and the long interregnum of phlogiston prevented! On what small oversights do great events in the history of science, as of nations, depend!"—Johnstone, Trans. Brit. Ass. vol. 7, p. 163.

of the anti-phlogistic doctrine. In 1785, Barthollet also adopted the new view. Fourcroy and Guyton de Morveau then joined the ranks, and, from this time forward, the anti-phlogistic theory continued to advance in public estimation. Its universal adoption may be said to close the second great epoch of chemical progress.

III.

THIRD CHEMICAL EPOCH—DISCOVERIES AND GENERALISATION OF LAVOISIER—NEW CHEMICAL NOMENCLATURE—DEVELOPMENT OF THE LAWS OF CHEMICAL COMBINATION—THE ATOMIC THEORY—CHEMISTRY BECOMES GRADUALLY ALLIED WITH MATHEMATICAL NOTATION, AND ASSUMES THE FORM OF AN EXACT SCIENCE.

No sooner was the phlogistic theory overthrown, than Lavoisier and his associates began to furnish that nomenclature of chemical bodies which, in all its essential particulars, still remains, although inconsistent with many facts at this time known. The nature and outline of this nomenclature are so well known as to render unnecessary any remarks on the subject. The nomenclature is one of great simplicity and beauty, but affords a striking instance of the disadvantage resulting from the adoption of theories as the ground-work of systematic arrangements. By a too hasty generalisation of a limited number of facts, the substance oxygen was assumed to be the universal former of acids, and hence its name. This assumption of the universal acidifying quality of oxygen, is a fault which lies at the basis of Lavoisier's nomenclature, and prejudices its structure. The greater number of acids, it is true, contain oxygen, but many are without it—and even those which contain it cannot logically be said to manifest the quality of acidity on account of any one special element in their composition.

The theory of Lavoisier affords, when contemplated in all its bearings, study for the psychologist no less than the chemist; characterising well that extraordinary period when a whole nation, convulsed to its very depths, shook off the trammels of political feudalism and scientific precedent, obliterating, with one fell swoop, theories, ordinances, institutions—daring to elevate human reason into a false infallibility. The nomenclature of Lavoisier may be designated as simple, beautiful, and arrogant. Not contented with reducing to classification members and species then known, it provided also for the classification of whole genera yet to be discovered, on the assumption of their conforming to the limited number of facts then known. This is its greatest fault. It is now time to advert to that interesting reduction of chemical phenomena to the form of mathematical expression which constitutes the science of stochiometry, and in which England, by the agency of Dalton, has appeared so honourably.

There can scarcely be a more interesting matter of contemplation to the philosopher, than the one involved in a comparison of inductive results with dawning speculations on similar subjects of imaginative writers.

Wide, even to infinity, as may appear at a first glance the space dividing imaginative speculations from induced facts, yet alliances have been frequently seen to exist where they might least have been expected.

Hypotheses, treated as mere poetic fancies in one age, scouted as scientific absurdities in the next—preparatory only to their being altogether forgotten—have often, when least expected, received confirmation from indirect channels, and, at length, become finally adopted as tenets, deducible from the sober exercise of induction.

So numerous are the instances of these poetic fancies of one age becoming realities in the next, that we are almost at length impelled, mentally, to inquire whether the imaginative creations of a healthy mind be so completely absolved from the influence of natural laws as would at first seem; whether the mental excursions of the past may not be guided by unseen forces to the shrine of truth, just as the celestial bodies are guided by an unseen gravitation!

The history of no science affords more striking exemplifications of this realization of poetic fancies than does that of the science of chemistry; and, especially, that portion of its history in connexion with the present subject—the gradual alliance of chemistry with number; the expression of parts entering into combination by means of formulæ.

From the earliest ages of civilized antiquity the ultimate composition of material things has been made the subject of speculative contemplation. Whether matter could be divided infinitely without limit, or whether a point in the operation of division might not be at length arrived at beyond which no further division could be carried, was early made the subject of philosophic discussion, and, indeed, very easily, though not necessarily, became allied with opposing theological dogmas.

The Peripatetics were the great advocates of the infinite divisibility of matter, whilst the Epicureans, on the other hand, maintained the contrary doctrine that a certain point existed, beyond which the process of division could no longer be carried. Hence, using, as we may with propriety, the language of modern chemistry for the purpose of designating these rival schools —the Epicureans may be said to have believed in an atomic theory and the Peripatetics in a non-atomic theory.

It would be unprofitable to discuss the numerous arguments which were employed by these two schools in support of their opposed doctrines. All of these arguments, save one, were propounded rather as dogmas than as based upon reason; but the excepted one is so essentially rational in its nature, and so specious in its appearance that it merits our consideration.

According to the peripatetic doctrine—a doctrine which amongst the moderns has been sanctioned by the high authority of Descartes—the hypothesis of assuming matter to be composed of atoms, or ultimately indivisible molecules, is absurd on obvious mathemamatical grounds; for it is easy to conceive a particle, however small, capable of subdivision to infinity, a notion altogether inconsistent with an assumption of the existence of atoms.

This argument is specious; but the possibility of its fallacy is obvious. The idea of continuous subdivision is not referable to a particle as matter, but as filling a position in space,—hence the idea of subdivision refers to space and not to matter. This distinction seems to have been apprehended by Zeno, who states in a paradoxical aphorism that, although a body is infinitely divisible, it does not consist of infinite parts. Nor was this distinction left unrecognised by the mathematical mind of Newton, who thus succinctly states his belief in the atomic constitution of the world. "It seems to me," he remarks, "that God, in the beginning, formed matter in a solid mass of hard, impenetrable particles; and that these primitive particles, being solids, are incomparably harder than any porous bodies compounded of them; even so very hard as never to wear or break in pieces, no ordinary power being able to divide what God made one in the first creation."

So little profit had accrued from the discussion of these two rival doctrines—so hopeless appeared the chance of arriving at truth by any line of demonstration, or of aiding by any train of plausible evidence even the wanderings of speculation, that philosophers by tacit consent allowed the question to remain at rest, until at length evidence in favour of the Epicurean or atomic theory was derived from a source whence it might have least been expected—from the domains of chemistry. Anterior to the period of the Saxon chemist Wenzell, in 1777, the opinion had prevailed that chemical combinations were not absolutely fixed and unvarying in composition.* Selecting, for example, the substance chloride of silver, it was consistent with the views of all chemists anterior to the time of Wenzell, to regard this compound not necessarily as being made up of a fixed invariable proportion of chlorine united with the metal silver. The remark is equally true as regards other compounds; therefore, had the exact composition of chloride of silver been known, the idea would never have occurred to chemists of this period to estimate the amount of chlorine existing in a solution, by determining the amount of silver with which it could unite. To Wenzell is attributable the credit of propounding the canon that, "*When two neutral salts decompose each other, the results are also neutral,*" a proposition which conveys within itself the doctrine of definite proportionalism; and is the starting point of a series of deductions, leading us in the end to an acquiesençe in the atomic theory.

The nature and tendencies of the discovery made by Wenzell will be best comprehended by limiting our observations to some specific case. Taking, then, the two neutral salts, sulphate of potash and nitrate of baryta, and mixing them in the exact proportions necessary to insure mutual decomposition, we obtain two neutral compounds as the result. This is shown by the subjoined diagram:—

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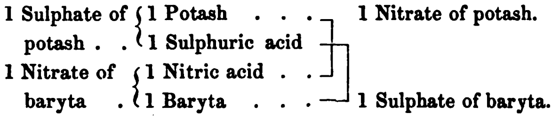
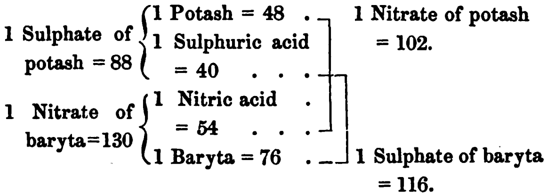
* Lehre der Verwandschaft.

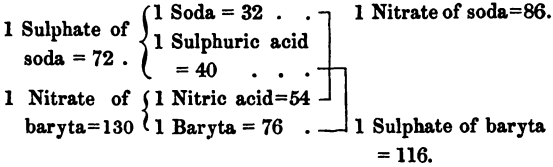


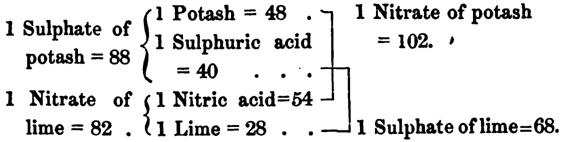
In which it is seen that the one proportional of sulphuric acid existing in sulphate of potash is exactly sufficient to neutralize the one proportional of baryta, and the one proportional of nitric acid of nitrate of baryta exactly sufficient to neutralize the one proportional of potash. In other words, in the solution which has served as the medium of decomposition, there does not exist any free sulphuric or nitric acids;—any free baryta or potash. Hence there must have been a mutual proportionality between the reacting compounds in the case under notice, and Wenzell demonstrated by experiment that a similar remark applied to every decomposition of parallel kind.

It is strange that Wenzell did not press to farther limits the curious fact made known by his experiments. Had he gone one step farther,—had he weighed the amounts of bodies decomposed, and weighed the results,—had he compared these weights as between two or more cases of decomposition, he could scarcely have failed to reap the honours which were reserved for Dalton twenty-six years later.

In order to illustrate the near approach made by Wenzell to a discovery of the laws of definite chemical combination, it will be sufficient to repeat the previous chart of decomposition, with the addition of the amount by weight of substances decomposed, together with the weighed amount of the results;—and to append a parallel case of decomposition, involving the use of two other salts, also indicating the parts by weight of substances decomposed, and their results.


1 Sulphate of potash = 88
1 Potash = 48
1 Sulphuric acid = 40
1 Nitrate of baryta=130
1 Nitric acid = 54
1 Baryta = 76
1 Nitrate of potash = 102.
1 Sulphate of baryta = 116.


1 Sulphate of soda = 72
1 Soda = 32
1 Sulphuric acid = 40
1 Nitrate of baryta=130
1 Nitric acid=54
1 Baryta = 76
1 Nitrate of soda=86.
1 Sulphate of baryta = 116.


1 Sulphate of potash = 88
1 Potash = 48
1 Sulphuric acid = 40
1 Nitrate of lime = 82
1 Nitric acid=54
1 Lime = 28
1 Nitrate of potash = 102.
1 Sulphate of lime=68.

A comparison between these charts of decomposition will render evident a nexus pervading the numeral equivalents of combination belonging to each substance represented in the diagrams. Thus it will be seen that 88 parts of sulphate of potash would have taken the place of 72 parts sulphate of soda in effecting the decomposition of 130 parts nitrate of baryta. That the quantity of sulphuric acid necessary to produce by decomposition 116 parts of sulphate of baryta, would have produced 68 parts sulphate of lime; and carrying the examination further, a circular nexus of numeral alliances would have been rendered manifest. This discovery was reserved for Richter of Berlin; who, extending his investigations to numerous compounds, drew up tables of decomposing proportionals, and in his "*Geometry of the Chemical Elements*," published between the years 1792 and 1802, arranged a series of tables showing the weight of each base capable of saturating 100 parts of each acid, and also the weight of each acid capable of saturating 100 parts of each base. He observed that in all these tables the bases and the acids followed the same order; and further, that the numbers in each table constituted a series of which the numbers had the same ratio to each other.

Thus Richter had succeeded in expanding to a considerable extent the first discovery of Wenzell, but he did not succeed in elevating it into a general law, involving the whole scope of chemical combination. For the list of substances operated upon, Richter demonstrated the existence of numeral decomposing proportionals, but he did not seem to have apprehended the universality of proportionalism which it has been the province of subsequent chemists to determine, and on the recognition of which hinge some of our most beautiful systems of chemical analysis.

The proportionality of chemical composition and decomposition attracted but little notice from the time of Richter until between the years 1803* and 1808,† when Dalton, speculating on the rational consequences of the facts made known by chemical decomposition, first promulgated a theory of atoms, based upon arguments no less rational and intelligible than the theory of Epicurus was irrational and obscure:—a theory which carries with it so many elements of conviction, that a celebrated modern chemist has concluded his arguments for and against the existence of atoms by the remark, "*that whether matter be atomic or not, thus much is certain, that granting it to be atomic, it would appear as it now does.*"

The arguments adduced by Dalton in favour of the existence of atoms, were such as these:—seeing that all marked cases of chemical combination can be demonstrated always to take place in definite proportion, and that by inference, a similar proportionality may be supposed to extend to less marked cases—seeing that these definite proportions of bodies entering into combination are mutually proportional amongst themselves, it follows that such definite immutability, such mutual proportionality, should most rationally be considered as indicating a ponderable ratio between combining elements; and that the ratio never changing would seem to be indicative of elementary ponderable molecules of determinate relative weight, unchanging, indivisible; qualities which will be recognised as fulfilling the definition of *an atom.*

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* Manchester Phil. Trans. for 1803.

† Dalton's New System of Chemical Philosophy.

With the view of practically illustrating the train of reasoning by which Dalton arrived at the conclusion that matter should be atomic, it will be well to fix on the exemplification afforded by some particular combining series. For this purpose none is more convenient than the one furnished by the oxygen compounds with nitrogen, of which there are five, as displayed by the accompanying table.*

	WEIGHT.		RATIO.	
	N.	O.	N.	O.
Protoxide of nitrogen . .	14	8	1	1
Binoxide of nitrogen . .	14	16	1	2
Hyponitrous acid	14	24	1	3
Nitrous acid	14	32	1	4
Nitric acid	14	40	1	5

A glance at this table will show the justice of the remark of M. Dumas,—that, granting matter to be atomic, it must necessarily combine as it is found to do. If, for instance, the ultimate molecule of nitrogen should weigh 14, that of oxygen weighing 8, then it should necessarily follow that, in a series of oxygen combinations with nitrogen, in which the amount of nitrogen remains fixed, the ratio of progressive increment of oxygen should be a ratio having for its arithmetical basis the number eight, of which every subsequent term should be a multiple by a whole number.

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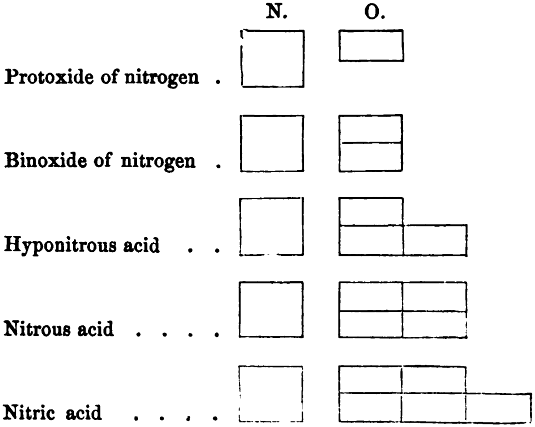
* It would nevertheless be unjust to the late Mr. Higgins, of Dublin, were the circumstance not mentioned that he had entered upon certain trains of reasoning which, if persevered in, must have conducted him to the discovery of Dalton. Mr. Higgins, in his comparative views of the phlogistic and anti-phlogistic theories, published in 1789, states, p. 36 and 37, that in volatile vitriolic acid, a single ultimate particle of sulphur is intimately united only to a single particle of dephlogisticated air; and thus, in perfect vitriolic acid, every single particle of sulphur is united to two of dephlogisticated air, being the quantity to saturation. A similar train of reasoning is applied by Mr. Higgins to the constitution of water, and the compounds of nitrogen and oxygen.

When we come to examine the volume as well as the weight of bodies entering into chemical combination, a definite order of progression will again be recognisable. Taking for instance the same five compounds of nitrogen and oxygen, and expressing by a diagram the rates of their combining volumes, the following result will be manifested :—



From the inspection of this diagram it will be evident that a ratio of measure as well as a ratio of weight exists between the combinations of oxygen and nitrogen; and the same remark applies to every combining series, the elements of which can be obtained in the gaseous form, and their volumes estimated.

It is evident that no indication afforded by the phenomena of definite chemical combination, can ever give us more than the *ratio* subsisting between the weight, and occasionally between the measure of *bodies* entering into chemical union. Granting, for the sake of argument, the postulate of the existence of atoms, they must be so exceedingly small that no one can hope to see them, or to have any other direct manifestation of their presence; hence the ratio only of their combining weight, and combining volumes, is all that phenomena of composition and decomposition will enable us to recognise. But the ratio subsisting between the dimensions of atoms involves some curious points of speculation. Referring to the preceding table, in which the ratio of combining volumes between compounds of oxygen and nitrogen is indicated, it will be observed that the assumed atomic size of oxygen is set down as half that of nitrogen; accordingly, starting with the assumption of the atomic size of oxygen being half that of nitrogen, the first member in the series of compounds of oxygen and nitrogen is considered to be a combination of atom to atom; but it would not be inconsistent with rational hypothesis, so far as facts of composition and decomposition are concerned, to set out with the assumption that the first compound in the series of oxygen and nitrogen is a compound of two atoms of nitrogen and one of oxygen, thus regarding the atoms of oxygen and of nitrogen as possessing equal dimensions. Indeed, certain chemists, especially on the continent, hold the opinion that the atomic dimensions of all bodies are equal; which assumption granted, it is evident that the lowest oxygen compound of nitrogen would be designated as a combination of two volumes nitrogen plus one of oxygen.

So far as we have the means of discovering, no direct evidence can be brought to bear in favour of either of these hypotheses: there are not wanting, however, strong presumptions in favour of the atomic volume of oxygen being half that of the atomic weight of nitrogen; evidence which will be best appreciated after investigating the phenomena of the decomposition of water. If this liquid be submitted to the agency of voltaic electricity, its two elements, oxygen and hydrogen, are liberated, one at either effective end (poles or electrodes) of the voltaic series; and in this case it will be found that the oxygen liberated will occupy a volume exactly half that of the associated hydrogen. Now, without entering upon discussions of the exact relation of electricity to the force which holds oxygen in combination with hydrogen, it must be accepted in the light of an ultimate fact, that the quantity of electricity involved in the decomposition, is an exponent of that force of decomposition, whatever it may be. Now, although there are two compounds of oxygen and hydrogen, viz., water and the peroxide of hydrogen, yet water alone is decomposable by voltaic electricity; and it has been demonstrated by Mr. Faraday, that in any series of binary combinations, only one is susceptible of direct decomposition by the voltaic current. Mere *à priori* reasoning would have bespoken credence for the supposition, that in any series of compounds the one most prone to suffer decomposition by voltaic energy would have been that which was least stable in its composition. Experiment, however, has demonstrated the very reverse of this, the most stable of a series being that which is susceptible of having its elements dissociated by the exercise of this power. This fact affords strong presumptive evidence of the atomic volume of oxygen being half the size of that of hydrogen, inasmuch as it would appear rational to assume that the most stable compound of a series should be an union of atom to atom.

It follows, by a continuation of this line of reasoning, that if water be a binary compound of atom to atom, not only must the atomic volume of hydrogen but also that of nitrogen, be double the atomic volume of oxygen; inasmuch as the smallest volume of nitrogen capable of uniting with the half volume of oxygen, is equal in measure to the smallest volume of hydrogen necessary to stand vicariously for it.

Hence it has been proposed to accept the result of voltaic decomposition as an indication of binary combination of atom to atom in doubtful cases; but it will be seen that the proposal is only based on a *highly probable* assumption.

From this short exposition of the primary laws of definite chemical combination, it will be recognised that the proportionality of composition and decomposition is a truth rendered manifest to our comprehension by evidence the most irrefragable; but the atomic constitution of matter, on which such proportionality is presumed to depend, still remains, and probably ever must remain, in the condition of a highly probable theory. As concerns the ratios of combining substances by weight, we have positive evidence; as concerns the ratios by measure, we have also positive evidence when the substances under combination are gaseous vapourous; but we have not yet, nor probably can we ever have, direct evidence as to the *absolute* weight of atoms, supposing them to exist. The question of the existence or the non-existence of atoms has been regarded as set at rest in the affirmative by most philosophers; the law of definite combination appearing sufficiently confirmatory of this view: nevertheless, such a conclusion would not seem *necessarily* deducible from the premises; for, although starting from the hypothetical assumption of atoms, the mind naturally arrives at the conclusion that combination of such atoms must necessarily be definite for any two series amongst themselves, and proportional in their decomposition for others,—yet the atomic assumption is by no means the only one consistent with such a result. The only postulates required by the circumstances of the case are those of *limitation* and of *proportionality*. That limitation, and this proportionality, may be of force, rather than of weight and extension,—qualities which may possibly be nothing more than an exponent and measurer of the former. This idea, in point of fact, would seem most accordant with certain remarkable numeral relations first indicated by M. Dumas; relations which promise to make known in a future era some remarkable connections existing between the chemical qualities of bodies and their mathematical exponents.*

Allotropism. Ozone. The hypothesis on which the alchemists conceived the transmutation of base metals into gold to be probable, consisted, as we have already seen, in this: that certain chemical substances were, in essence, the same; consequently, one essence might be susceptible of change by man's ingenuity into several conditions. No sooner, however, was chemistry established as a science, than the notion of the alchemists became repudiated as utterly untenable and absurd. The canon was laid down that matter consists of a limited number of elements, which, by the operation of no existing law, admitted of mutual transformation. On the acceptation of this canon the whole scheme of chemical analysis is built.

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* These curious relations are discussed by Mr. Faraday, in his Lecture on "Chlorine, Bromine, and Iodine;" to the end of which lecture is appended an abstract of the paper of M. Dumas.

And here it will be necessary to ascertain the force and limitation of the terms *identity* and *mutual convertibility,* inasmuch as a slight reference to common phenomena will be sufficient to assure us that bodies, even composed of simple elements, according to the best testimony of existing chemistry, are susceptible of modifying the aspects under which they present themselves to our senses. Thus, for example, iodine, a simple body, as we now believe, may come under our notice as a crystalline solid or a violet-coloured vapour; bromine may present itself as a liquid or a vapour; chlorine as a liquid or a gas; carbon, amorphous, black, opaque, as in charcoal—crystalline, colourless, transparent, as in the diamond.

In all these cases there is a manifest difference of physical quality; yet such metamorphoses of physical condition being easily referable to the direct expansive influence of heat in some cases, to the exercise of crystalline force in others, did not awaken in the minds of chemists any suspicion that the canon of the immutability of matter might have to be received with limitations. Nor had there been unknown to chemists, for a period too long to admit of its being indicated with certainty, at least one other fact, involving a remarkable change in the manifestation of the elementary body, sulphur; a change neither referable to crystalline force, nor to the direct influence of temperature: a fact now recognised as furnishing a striking instance of the existence of matter in two well-marked physical conditions, but which, until lately, passed without an attempt at analysis or speculation. The usual physical characteristics oı sulphur are too well known to need recapitulation. Exposed to a temperature of 226° F., it fuses, and if maintained in fusion at this temperature, or any point beyond it not exceeding 300° F., then suddenly thrown into water, and the result examined, the aggregated mass will be found identical in all respects with the original material. If, however, instead of pouring out the sulphur at the points of fusion above mentioned, the source of heat be still continued, first the material becomes black and almost solid,—its point of fusion is visibly elevated, and it can only be reconverted into the liquid state by a still further increasement of temperature. If now, as soon as liquidity has been established, the fused material be poured into cold water, a very curious result is manifested. The sulphur cools, maintains its dark colour, and, instead of being brittle and yellow as before, its physical condition resembles that of heated glue, or very much softened indiarubber. And this is not all: its medicinal qualities are affected, as recent investigations have proved. Nor is this the only manifestation of a dual existence (if the term be admissible) afforded by sulphur. It is susceptible of crystallisation in two *non-convertible forms:* an expression which requires some explanation. The Abbé Haüy, one of the first who aggregated the disjointed facts of crystallography into a science, demonstrated that, however various the numerous crystalline forms of nature and of art might be, these were, nevertheless, susceptible of being grouped into systems, each possessing its own allied and derivative forms, capable of mutual variation amongst themselves for each system, but the forms of one system never assuming those of another.* Now sulphur, by assuming the crystalline form of two distinct systems, belongs to the class of dimorphous bodies. If exposed to heat, and the evolved vapour be crystallised by slow cooling, or if dissolved in bisulphuret of carbon, and the solution crystallised, rhombic octohedra result; if melted and slowly cooled, oblique rhombic prisms. The allotropic condition of phosphorus is still more remarkable, on account of the violently marked characteristics of ordinary phosphorus, and the inactivity of the derivative. It was discovered by Professor Schrötter, of Vienna, and the history of its discovery is as follows.

If common phosphorus be ignited in the open air, or heated in a vessel to which the access of air is limited, a certain amount of red coloured substance results. This body had long been noticed by various experimenters, and was almost universally announced to be a combination of phosphorus with oxygen, in a ratio smaller than that necessary to create an acid; accordingly it was termed oxide of phosphorus. Professor Schrötter appears to have been the first investigator who made this substance an object of special study,* and he succeeded in proving, by some very decisive experiments, that the substance in question could not be an oxide of phosphorus, inasmuch as it was susceptible of generation under circumstances involving the total absence of oxygen in any form—for example, in a closed vessel to which atmospheric air could not gain access; also when surrounded with hydrogen, or nitrogen. Berzelius, then living, seems to have been the first to suggest the condition of allotropism, as influencing the resulting change; an explanation which is now universally received, and which, indeed, seems to be inevitable.

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* The systems of classification usually adopted in crystallography are those of Weiss, Mohs, and Naumann, which differ in certain particulars amongst themselves, but all of which adopt, as the basis of classification, the order of arrangement assumed by crystalline particles with respect to certain lines or axes drawn through the crystals.

A detailed account having been given of the qualities possessed by this condition of phosphorus in the ensuing fifth lecture, and the remarks which accompany it, a slight notice of these qualities will only be necessary in this place, more for the sake of examining the force of certain speculations which arise in reference to allotropism considered in the abstract, than of detailing the qualities of allotropic phosphorus. The greatest dissimilarity is manifested between the ordinary and allotropic condition of this element. Common phosphorus is yellowish, pliable, soft; allotropic phosphorus is almost black, brittle, hard. Common phosphorus has a powerful smell and taste—is poisonous, dissolves readily in bisulphuret of carbon; allotropic phosphorus is devoid of both smell and taste—devoid, also, so far as we know, of poisonous agency, and insoluble in bisulphuret of carbon. Common phosphorus can scarcely be handled with impunity, and bursts into flame at a temperature little above that of the human body; allotropic phosphorus may be handled without any fear of danger—may even be carried in the pocket, as Professor Schrötter is in the habit of carrying it, and so far from readily bursting into flame, we have no evidence that it is combustible, for, at a temperature slightly above 600°, it changes to common phosphorus, when, of course, it is subjected to the usual laws of combustion and otherwise to which that substance is amenable. We can scarcely imagine to ourselves a more complete opposition of qualities than is here presented in the two conditions of phosphorus: an opposition not limited by mere physical manifestations of density or crystallographic form, but recognisable through all the phases of solution, thermal demeanour, and physiological effect. The metamorphosis has, in fact, been so complete, that we can only demonstrate the allotropical substance *to be* phosphorus by reducing it to its original state, and subjecting it to ordinary tests. If the forces determining its constitution had been so balanced that the power of reduction were denied to us, then the substance we now call *allotropic phosphorus* must necessarily, according to the strictest propriety of logic, have been admitted to be not phosphorus, but some other body. It is impossible, rationally, to deny that such permanent inconvertibility may not lie within the power of natural laws to effect. That we are not aware of such an example cannot be accepted as a proof of its non-existence; and analogy, the guidance to which we refer when direct testimony fails, is in favour of the affirmative.

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* Vide Erdmann's Journ. für Praktische Chem., Band 52, 53, 54.

The next extraordinary example of allotropism which modern science presents us with is ozone, or ozonised oxygen, a substance, to the discovery of which, and the development of its qualities, we are indebted to M. Schönbein, of Basle.*

From time immemorial atmospheric influences have been known to develop a bleaching effect, although the atmospheric constituents, oxygen and nitrogen, either alone or in combination, are endowed with no such energy. Within the last few years, however, M. Schönbein has succeeded in developing a second allotropic condition of oxygen—the bleaching effects of which almost vie with those of chlorine, and the agent itself differs in such remarkable particulars from common oxygen that M. Schönbein was at first induced to consider it a gaseous oxide of hydrogen. However, seeing that it could be formed without the access of hydrogen, or anything containing that element—seeing that no hydrogen could be extracted from it by the most refined chemical means, there remained no alternative but to regard it as an allotropic condition of oxygen.

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* For details concerning ozone, see the following:—Erdmann's Journ., vol. 50, p. 259; vol. 52, pp. 135, 183; vol. 53, pp. 51, 65, 321, 501; vol. 54, p. 65.

Nor according to M. Schönbein is this allotropic state limited to oxygen in the condition of gas. It is an opinion of this philosopher, and one seemingly well authenticated by facts, that oxygen enters into combination occasionally in its allotropic state. Thus, for instance, in the peroxide of lead which consists of one equivalent of lead, plus two of oxygen. M. Schönbein believes the second equivalent to exist in the condition of ozone. Extending his theory from the range of mere specific phenomena to include whole genera, M. Schönbein believes that the ozonised tate of oxygen is that which invariably precedes all permanent combinations of that element with another; and that many of the bleaching effects supposed to result from different agencies, are referable to the operation of ozone. Thus, for instance, the bleaching quality possessed by sulphurous acid is, according to M. Schönbein, ultimately referable to ozone; and he has succeeded in proving that sulphurous acid does not, except it be in contact with air or moisture, give rise to any permanent bleaching

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effect. In making this statement, he distinguishes between the permanent and the transient effects of sulphurous acid, and refers them to two essentially different operations. For instance, the experiment is well known of changing a red rose to a white one, simply by holding it over an ignited brimstone-match, or exposing it in any other way to the agency of sulphurous acid. This effect, however, is transient; the original red colour being easily caused to return by the contact of many acids and oxidizing bodies. This class of bleaching is, according to M. Schönbein, analogous to that produced on blue indigo by the operation of deoxidising bodies, and referable to a similar cause. There are many ways of changing oxygen gas into its allotropic or ozonised state. The most direct, although not the most convenient, consists in transmitting through it a succession of electric sparks. A peculiar odour is under these circumstances developed, and which has been denominated the electric smell. This odour is due to the presence of ozone, largely diluted with atmospheric air. In a more concentrated state, ozone partakes of the odour of chlorine, and powerfully affects the respiratory organs. Small animals put into an atmosphere of it rapidly die, hence its presence in any considerable quantity in the atmosphere must be very injurious to the animal economy.

Not only is ozone produced when electrical sparks are transmitted through the air, but also when water is electrolyzed, as in the case of a dilute solution of sulphuric acid, or sulphate of zinc; or when phosphorus acts at common temperatures on a moist portion of the atmosphere. To generate ozone by the latter method it suffices to take a piece of clean phosphorus, about half an inch long, and from which the external crust has been removed by scraping; the phosphorus is now put into a clean two-quart bottle, at a temperature of about 60° F., with as much water as will half cover the phosphorus; the mouth of the bottle is now to be slightly closed,—so that if the phosphorus should inflame, no harm may result,—and set aside. The formation of ozone takes place rapidly, being indicated by the luminous condition of the phosphorus, and the ascent from it of a fountain-like column of smoke. In less than a minute Schönbein's ozone test, presently to be mentioned, will demonstrate the existence of ozone in the air of the bottle; and in five or six hours, its presence will be abundant. The phosphorus now being removed, and the aëreal contents washed, the bottle containing ozone may be set aside for experiment.

The test for ozone is as follows: 1 part of pure iodide of potassium, 10 parts of starch, and 200 parts of water are to be boiled together for a few moments. A little of this preparation placed on writing paper with a brush being introduced into the ozone atmosphere, is rendered instantly blue from the evolution of iodine;—or if bibulous paper be dipped into this solution, and then dried, it forms Schönbein's ozonometric test: for a slip being introduced dry into an atmosphere supposed to contain ozone, after remaining there a longer or shorter time, on being removed and then moistened, instantly becomes more or less deeply blue if ozone be present.

Ozone, when obtained by the three very different processes described, is identical in every respect: its properties are as follow:—It is a gaseous body of a very peculiar odour: when concentrated, the odour approaches to that of chlorine; when diluted, it cannot be distinguished from what is called the electric smell. It is insoluble in water. Like chlorine, bromine, and the metallic peroxides, it is a powerful electromotive substance. It discharges vegetable colours with a chlorine-like energy. It converts phosphorus ultimately into phosphoric acid; it combines with chlorine, bromine, and iodine; it does not unite with nitrogen under ordinary circumstances, but does when lime-water is present; and nitrate of lime is formed, from which nitre may be readily obtained. At common, and even at low temperatures, it acts powerfully upon most metallic bodies, producing the highest degree of oxidation they are capable of. Lead and even silver are carried at once to the state of peroxides; arsenic and antimony produce arsenic and stibic acids. It transforms many of the lower oxides into peroxides; thus, the hydrate of the oxides of lead, cobalt, nickel, and manganese become in it peroxides: the basic oxide of silver undergoes the same change. It decomposes rapidly the solid and dissolved protosalts of manganese; the hydrated peroxides of the metal being formed, and the acid of the salts evolved. It decomposes the solution of the tribasic acetate of lead; the peroxide of that metal and the ordinary acetate being formed. It rapidly converts the protosalts of iron and tin into persalts. It destroys many hydrogenated gaseous compounds: the combinations of hydrogen with sulphur, selenium, phosphorus, iodine, arsenic, and antimony are thus affected. It appears to unite chemically with olefiant gas in the manner of chlorine. It instantly transforms the sulphurous and nitrous acids into the sulphuric and nitric acids, and the sulphites and nitrites into sulphates and nitrates. It changes many metallic sulphurets (as those of lead and copper) into sulphates. It decomposes many iodides in their solid and dissolved state. By its continued action, iodide of potassium becomes converted into iodate of potassa. It changes both the crystallised and dissolved yellow prussiate of potassa into the red salt, potash being evolved. It produces oxidising effects upon most organic compounds, causing a variety of chemical changes; thus, guaiacum is turned blue by it. From the above enumeration it would appear that ozone is a most ready and powerful oxidiser, and in a great number of cases acts like Thenard's peroxide of hydrogen, or chlorine, or bromine.

When an ozonised atmosphere is made as dry as possible, and then sent through a red-hot tube, the ozone disappears, being converted apparently into ordinary oxygen, and no water or any other result is produced.

In addition to the methods indicated, there are yet other means of obtaining ozone. Thus, for instance, if into a jar filled with ether vapour, a heated wire or glass rod be immersed, ozone is produced, and will be immediately evidenced by the test. Moreover, when solutions of tartaric acid, certain oils, turpentine, &c., are exposed to air and light for a considerable time, they manifest a powerful bleaching effect, attributed by M. Schönbein to the generation of ozone.

The experiments of the philosopher in reference to oil of turpentine, are especially interesting. He found that when totally deprived of oxygen, which he accomplished by digestion with protosulphate of iron, it no longer possessed any bleaching effect, and its smell was altered, presenting great analogy in this respect to oil of peppermint; gradually, after exposure to heat and light, under occasional agitation, oxygen became absorbed, and the bleaching effect was renewed. Certain experiments of M. Osann,* will, if confirmed, still further disturb our pre-existing ideas of chemical combination, and increase our interest for ozone. He believes that in certain cases when this allotropic condition of phosphorus by combination assumes a solid form, it does not combine in the ratio of 8, on the hydrogen scale of unity—the ratio of oxygen, but in the ratio of only 6. The property of this conclusion, however, has been denied by M. Schönbein, on grounds which appear incontrovertible. This sketch of the progress of allotropism, by reference chiefly to the history of phosphorus and oxygen, will seem to present a general idea of the most remarkable revolution in chemical opinions, which has occurred since the abolition of the theory of phlogiston.

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* Osann Ueber Ozen-Sauerstoff, Erdmann's Journ., Band 53 Heft I., Seite 51.

On chemical symbols and notation. In every science as it becomes developed, certain devices are found requisite for conveying facts to the memory by condensed expressions and formulæ, which not merely obviate the trouble of circumlocution, but by enabling the senses to take in a large range of subjects at once, materially increase the power of comprehension. Accordingly, a system of abbreviated notation has become general in all chemical treatises, and although opposed on its first introduction, is now valued commensurately with its merits.

Symbolic notation is so far from being new in chemistry, that we find it to have been a system adopted by the alchemists, rather for the purpose, however, of communicating amongst each other in a mystic language, unknown to the multitude, than with a view to any kind of utility. Moreover, the alchemical symbols were far too limited in their application, to admit of being incorporated with modern chemistry; having merely sufficed for characterising the metallic bodies then known.

The first attempt at modern symbolism as an aid to chemical study was made by Mr. Dalton about 1806, soon after the idea of an atomic constitution of matter had presented itself to him. His system consisted in representing elementary substances by little circles, variously marked, so as to be readily distinguishable from one another,—and admitted of combinations illustrative of the presumed manner in which certain compounds are formed by the union of their elements. Thus the symbol for hydrogen was ⊙; for nitrogen ⦶; for oxygen ○; and carbon ●; whilst other simple bodies were represented when necessary by a circle made to include the initial of the body represented; thus, Ⓢ would represent sulphur; (si) silica, &c.

According to the system of Dalton, the compounds, water, carbonic oxide, binoxide of hydrogen, and carbonic acid, were represented as follow:—

○ ⊙ Water.
○ ● Carbonic oxide.
○ ⊙ ○ Binoxide of hydrogen.
○ ● ○ Carbonic acid.

This system of notation however, was not of the slightest use to chemistry. It presented the radical disadvantages of being cumbrous, of expressing the composition of bodies according to hypothetical notions of the arrangement of their particles, and of being totally incompetent to deal with the more complex results of chemical union. Hence, it never came into use even here, where the fame of the illustrious Dalton predisposed so much to its reception. Meantime, chemistry began to unfold the riches of its combinations with greater rapidity than the most sanguine had contemplated. Compounds resulted, with the expression of whose constitution the nomenclature of Lavoisier was totally insufficient to grapple. Symbolical notation became more and more desirable; and, lastly, so soon as organic chemistry began to be cultivated as a distinct field of chemical inquiry, than to remain any longer without comprehensive formulæ was not possible.

On no one was this conviction more strongly impressed than the lamented Berzelius, who applied himself to the development of a symbolical notation, that should be applicable, not only to simple cases of combination, but to even the most complex. It has been termed the algebraical system of chemical notation, but somewhat incorrectly. All the similarity consists in the equational form of expressing composition and decomposition—a mode of expression equally possible with the symbols of Dalton, although not so compendiously.

The system of Berzelius sets out with the indication of every elementary body by a certain letter or letters—initial letters when it is possible to use them without confusion—in other cases short combinations of letters. A table of these abbreviations will be given further on.

Further abbreviation is accomplished by the introduction of certain conventional signs, more particularly as regards bodies of the organic kingdom. Thus, water may be indicated as $= \mathrm{Aq.}$, instead of $= \mathrm{HO}$, hydrogen and oxygen; cyanogen as $= \mathrm{Cy}$; tartaric acid, $= \bar{\mathrm{T}}$; citric acid, $= \bar{\mathrm{C}}$; acetic acid, $= \bar{\mathrm{A}}$; and generally any vegetable acid may be shortly indicated by using its initial letter dashed *over*. On the other hand, vegetable alkalis may be indicated by placing a cross over their initial letter, and other literal representative. Thus, Quina may he indicated by $\overset{+}{\mathrm{Ch}}$ (*i.e.* China); morphia by $\overset{+}{\mathrm{M}}$; oxide of lead, PbO, *i.e.*, plumbum and oxygen; potash, KO, *i.e.*, kalium, or potassium, and oxygen.

In these and other cases, where single equivalents enter into combination, the usual algebraical rule is followed of appending no numeral of unity, which is always implied. When, however, more than single atoms enter into combination, the employment of numerals becomes indispensable. Thus sulphuric acid, which is a combination of 1 equivalent of sulphur with 3 of oxygen, is thus expressed, SO^3, or SO_3; some chemists preferring to write the 3 inferiorly, so as to make a distinction between it and an algebraic power. In this form of expression the 3 only refers to the quantity of one of the elements in the binary compound, namely, oxygen. Had we occasion to indicate symbolically 3 equivalents of sulphuric acid, it would be accomplished thus, $3SO_3$; and, generally, all large figures on the left of a symbolical expression affect the whole constituents of that expression; whereas, small figures on the right affect merely the element to which they are immediately attached.

As binary compounds of elements are indicated by putting symbolical initials in juxta-position, so the comma and the plus sign + are employed to designate ultimate combinations arranged in proximate series.

Thus, PbO indicates lead; SO_3 sulphuric acid; and PbO,SO_3 or $PbO+SO_3$ indicate a proximate union of sulphuric acid with oxide of lead, to form sulphate of oxide of lead, commonly termed sulphate of lead. The bracket, or vinculum, in accomplishing symbolical notation, is similar in its use to the application of the same in algebra. Thus, $3PbO+\bar{A}$ indicates a compound of 3 equivalents of oxide of lead with 1 of acetic acid, the tribasic acetate of lead: whereas, $3(PbO+\bar{A})$ means 3 atoms of neutral acetate of lead.

Such is the *principle* on which the symbolism of chemical combination was effected by Berzelius. This great chemist, however, effected still further abbreviations, which have only been partially disused on account of the practical difficulty of printing them, the signs having to be made specially as an addition to the printer's fount. Nevertheless the system is eminently convenient and expressive. It is still employed by many chemical writers. It consists in representing sulphur and oxygen (the two most frequently occurring constituents in compound bodies) by means of commas and dots placed over a letter representing the other constituents. Thus, $\dot{H}$ would represent water, according to the usual English theory of regarding it as a binary compound of oxygen and hydrogen, although Berzelius represented it as $=\ddot{H}_2$; inasmuch as he adopted the theory of its being a compound of two atoms hydrogen plus 1 of oxygen. Sulphuric acid would be represented as $=\dddot{S}$, and so on for other bodies.

INTRODUCTION TO LECTURE I.

OXYGEN—ITS SYNONYMES AND ETYMOLOGY, HISTORY, NATURAL HISTORY, PREPARATION, AND QUALITIES.

Synonymes.—Oxygen, *οξὺς*, acid, *γένναω*, I produce. (Lavoisier).

Dephlogisticated air. (Priestley).
Empyreal air.
Vital air.

History.—Oxygen gas was discovered by Priestley, August 1, 1774, who called it *dephlogisticated air*. In the following year it was again discovered by Scheele, without cognizance of the previous discovery by Priestley.

Distribution and Natural History.—Oxygen, of all substances, is most largely found distributed throughout nature, constituting at least three-fourths of the known terraqueous globe. It exists both in the inorganic and organic kingdom. In the former it constitutes eight-ninths of water, and water covers about three-fourths of the surface of the earth. Of the solid crust of the globe, at least one-third is oxygen, as will be rendered manifest on considering the materials of which the crust is formed, namely, for the most part of *silica*, *carbonate of lime*, and *alumina*. Silica alone constitutes 45 per cent. of the earth's mineral crust. Of the dry atmosphere oxygen constitutes twenty-three parts in one hundred, and eight-ninths of atmospheric vapour.

In the organic kingdom oxygen is an essential constituent of all living beings.

PREPARATION OF OXYGEN GAS.—*Process I.*—By exposing to heat in a small glass retort the peroxide of mercury, when oxygen gas is eliminated, and metallic quicksilver condenses in the upper part of the tube. Oxides of gold, silver, platinum, and mercury are those only which yield up the *whole* of their oxygen on the application of heat. Many other oxides yield up a portion of their oxygen by similar treatment. The method of generating oxygen gas from the peroxide of mercury is seldom had recourse to at this time, seeing that it is more expensive and less convenient than many other processes. It possesses great interest, however, in consequence of its having been the original process by which oxygen gas was developed by Priestley, and as beautifully illustrating by analysis the composition of oxides.

A very curious circumstance in relation to the oxide of mercury may here be indicated. At a certain temperature, this material, as we have seen, yields up its oxygen, and leaves metallic quicksilver; but if metallic quicksilver be exposed to a lower temperature, oxygen is absorbed and peroxide of mercury formed. Taking advantage of this principle, M. Boussingault has recently proposed to abstract large stores of oxygen gas from atmospheric air, and to liberate them for economic uses. He does not employ mercury for the purpose, but caustic baryta, which at one grade of temperature absorbs an additional dose of oxygen, becoming peroxide of barium, and at an additional grade evolves the same. Thus, he causes one charge of caustic baryta to alternately absorb oxygen from the atmosphere, and evolve it into a reservoir.

Process II.—By exposing to a red-heat binoxide or peroxide of manganese in an iron retort.

Theory of the Process.—Manganese in acid, to its acid combinations, forms with oxygen three oxides, viz.:—

	Manganese Equivalents.		Parts by Weight.	
	Ma.	Ox.	Ma.	Ox.
Protoxide of manganese	1	1	28	8
Sesquioxide of manganese	1	1½	28	12
Binoxide or peroxide of manganese .	1	2	28	16

In the binoxide half an equivalent of oxygen is so loosely combined that it is evolved on the application of heat, and sesquioxide of manganese remains. This is the process universally had recourse to when oxygen gas is required in large quantities. But in consequence of the impurities of native binoxide of manganese, the resulting oxygen is always contaminated.

Process III.—By distilling in a glass retort a mixture of binoxide of manganese and sulphuric acid.

Theory of the Process.—In this decomposition there is afforded an example of what is termed by some chemical writers, *disposing affinity.* Binoxide of manganese does not combine with sulphuric acid, but protoxide unites readily. Hence, the former may be said to evolve half its amount of oxygen, in order that it may become the latter, to fulfil the condition of union with sulphuric acid. In treating of these cases of disposing affinity, we should remember that, although language obliges us to treat of phases of decomposition as consecutive, they are in reality not so, but simultaneous.

The decomposition may be thus illustrated by means of a diagram, and to avoid the occurrence of half equivalents, two equivalents of binoxide of manganese are assumed to be under decomposition.

$$\begin{array}{l}\text{2 Binoxide of}\\ \text{Manganese}\\ = 88.\end{array}\left\{\begin{array}{l}\text{1 Oxygen} \quad = 8 \text{ ————— } \Delta \text{ is evolved.}\\ \left.\begin{array}{l}\text{3 Oxygen} \quad = 24\\ \text{2 Manganese} = 56\end{array}\right\}\begin{array}{l}\text{2 Sesquioxide of}\\ \text{Manganese} = 80.\end{array}\end{array}\right.$$

Process IV.—By the electrolysis, or voltaic decomposition of water; the two resulting gases, hydrogen and oxygen, being separately collected. It is generally had recourse to as the means of demonstrating the composition of water by analysis, or for the purpose of obtaining oxygen absolutely pure.

Theory of the Process.—When water is thus decomposed, oxygen goes to the positive end or pole of the voltaic arrangement, hydrogen to the negative end. Davy, speculating on the bearings of this result, inferred that oxygen contained in itself a negative, and hydrogen a positive electro quality, inasmuch as it can be demonstrated that opposite electricities are mutually attractive of each other. Hence, oxygen was termed an electro-negative, and hydrogen an electro-positive element. The investigations of Mr. Faraday have proved that the above simple theory of voltaic agency on water is untenable; that electricity, although in some way connected with and producing the decomposition, does not act in the simple manner assumed by Davy. Mr. Faraday has also proved that the terms electric attraction are misapplied in the explanation of this and similar phenomena; and hence, that the term poles, a term indicative of localised powers, is improper. The so-called poles are merely doors, or thoroughfares, through which the electric influence passes; hence, Mr. Faraday has suggested for them the appropriate name of odes, from *οδος*, a door or way; and for the purpose of individualising these odes, or pathways, of electric influence, the Greek terms *ανα* and *κατα* have been applied. Thus, the compound word *anode* may be regarded as synonymous with *positive pole*, and *cathode* with *negative pole.*

The introduction of these terms suggests the propriety of others, as will be recognised. Thus, to say that oxygen is electro-negative, or that hydrogen is electro-positive, is so far inconsistent with the correctness of philosophic diction that it reposes on two assumptions; firstly, that there exist, mutually attractive and repulsive terminals (poles); secondly that the liberation of hydrogen at one of these terminals and oxygen at the other is the result of attraction.

That they are thus attracted is a position which has never been demonstrated; that they go there is merely the expression of a fact. Hence Mr. Faraday terms them, and all bodies which act similarly in regard of voltaic electricity, *ions,* from ἰεμι, I go. Hence arise the compound words, an-ions and cat-ions, or, for euphony, cath-ions. A cathion is that which goes to the cathode (or negative pole); an anion that which goes to the anode (or positive pole). Hence, oxygen is an anion, hydrogen a cathion. The whole operation of a voltaic decomposition similar to that of water, is termed electrolysis, from ελεκτρον and λυω, I loosen.*

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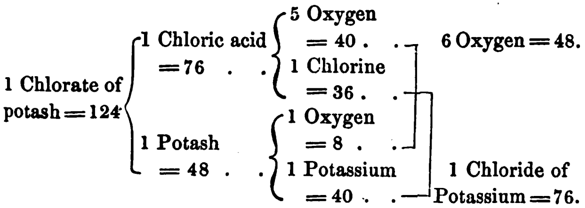
* For details of the chemical powers of the voltaic pile, the reader may consult—

1. A paper by Messrs. Nicholson and Carlisle in the Phil. Mag. for 1800, and Nicholson's Journal, 4to., iv. 183.
2. Hisinger and Berzelius (Gehlen's Journal, i. 115).

Process V.—By distilling the salt chlorate of potash in a retort of hard glass.

Theory of the Process.—Chlorate of potash is composed of chloric acid and potash. Chloric acid contains 5 equivalents of oxygen to 1 of chlorine, potash 1 equivalent of oxygen to 1 of potassium. Therefore, every equivalent of chlorate of potash contains 6 equivalents of oxygen, all of which are given off by the application of heat, chloride of potassium remaining in the retort.

The rationale of the process is thus exemplified by a diagram :—


1 Chlorate of potash = 124
1 Chloric acid = 76
1 Potash = 48
5 Oxygen = 40
1 Chlorine = 36
1 Oxygen = 8
1 Potassium = 40
6 Oxygen = 48.
1 Chloride of Potassium = 76.

Process VI.—By heating in a glass retort a mixture of equal parts chlorate of potash and black oxide of copper, or binoxide (*black oxide*) (*peroxide*) of manganese.

Theory of the Process.—Similar to the above, only the heat necessary to effect decomposition of the

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3. Davy on some chemical agencies of electricity. Phil. Trans., 1807.

4. Faraday's experimental researches on electricity. Phil. Trans., 1832, *et seq.*

chlorate of potash is much less, the oxide of copper or of manganese promoting the decomposition by *catalysis*.

The process of distilling chlorate of potash furnishes oxygen gas in a state of complete purity; but the heat necessary to effect decomposition of the chlorate is almost too high for glass vessels to withstand, and is therefore inconvenient. By incorporating with the chlorate some black oxide of copper, or binoxide of manganese, the evolution of oxygen gas is made to take place with great facility on the mere application of a spirit-lamp flame. Whether the oxide of copper or of manganese be employed, no chemical action is exercised between either and the chlorate of potash; but the rapid evolution of oxygen from the latter is referred to the list of phenomena termed "catalytic," and concerning which there will be found some remarks in Professor Faraday's Lecture on hydrogen.

PROPERTIES.—Oxygen, in its uncombined state, is generally met with under the aspect of a colourless, tasteless, inodorous, invisible gas, which is not combustible, but a good supporter of combustion, and the results of such combustion are either acids, alkalies, or neutral bodies, simply termed oxides. It is devoid of alkaline and acid reaction, though entering into the composition of both acids and alkalies, and may be distinguished from every other gas, with the exception of protoxide of nitrogen, or nitrous oxide, or laughing gas, by plunging into it an incandescent though non-flaming chip of wood, which immediately bursts into flame. Oxygen gas is essentially the supporter of animal life, yet no animal can live for a protracted time in undiluted oxygen. Assuming water to be the protoxide of hydrogen, then it follows that the atomic or combining volume of oxygen gas is only half that of hydrogen. One hundred cubic inches of oxygen gas under a barometric pressure of 30 inches, and at a temperature of 60° F., weigh 34·6 grains; 100 cubic inches of air, under similar conditions, weighing 31·0117 grains. Hence, the specific gravity of oxygen, air being = unity, will be equal to 1·111. It is 16 times heavier than hydrogen gas, but its combining volume being only half the combining volume of hydrogen, it follows that, considering hydrogen to be the unity of atomic comparison, the atomic or equivalent weight of oxygen will be = 8; and here it may be remarked that a consideration of the combining volume of gases, and of their combining weights, furnish the data, when taken in connection with the specific gravity of hydrogen, for indicating the specific gravity of any particular gas. If the atomic or combining volumes of all gases were equal, then the numeral ratio of their atomic weights would be also the ratio of their specific gravities; but as the combining volumes of gases are unequal—are, viz., oxygen possessing a combining volume half that of hydrogen, and several others double that of hydrogen—this circumstance must be made an element in the calculation.

Applying the rule to determine the specific gravity of oxygen, the operation is as follows :—

[*]
$$\begin{array}{r l} 0{\cdot}69\dot{4} & = \text{specific gravity of hydrogen.}\\ 8 & = \text{atomic weight of oxygen.}\\ \cline{1-1} 5{\cdot}55\dot{5} & = \text{half the specific gravity of oxygen.}\\ 2 & \\ \cline{1-1} 1{\cdot}111 & = \text{specific gravity of oxygen.} \end{array}$$

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[*] Possibly, according to modern researches, 0·693.

LECTURE I.

ATOMIC WEIGHTS OF THE NON-METALLIC ELEMENTS.

Oxygen	8	Bromine	78	Sulphur	16
Chlorine	36	Hydrogen	1	Phosphorus	32
Iodine	126	Nitrogen	14	Carbon	6

NOTES OF MATERIALS AND APPARATUS REQUIRED DURING THE LECTURE.

Mixture of chlorate of potash with oxide of manganese, glass retort, spirit-lamp, ring-stand, pneumatic trough, and glass jars.

Bottles and jars of oxygen.

Table of the weight of oxygen.

Binoxide of nitrogen in jar over a pneumatic trough. Prove that it is a test for oxygen; then prove the existence of oxygen in the atomspheric air.

Phosphorus (clean) in a funnel; phosphorus (clean) in a bottle; with a little water for the production of ozone. Phosphorus, and a little disc of chalk on which the phosphorus may be lighted.

A jar of oxygen for displaying the combustion of phosphorus. A jar of oxygen for displaying the combustion of charcoal.

Bottles of ozonized air, and mode of its preparation.

Paper imbued with iodide of potassium and starch. Silver leaf in bottle.

Ether-jar and hot glass rod.

The ozonometer of Schönbein described.

Specimens of rock crystal. Flint sand. Tables of their composition.

Specimens of granite, clay, slate. Silicified wood.

Phosphorus thrown into water. Potassium thrown into water.

Specimens of nitre and of chlorate of potash. Tables of their composition.

Chlorate of potash and sulphuret of antimony or sugar.

Sulphuric acid.

ALTHOUGH in these lectures it has never been professed by the directors of the Royal Institution to present a strictly systematic course of instruction, yet it has been always considered an object to avoid adopting the opposite course. It has been thought desirable also to avoid desultory teaching, and to so arrange the various discourses that, although delivered by various persons, and on various subjects, they may yet form an alliance with each other, and present a tolerably connected scheme in the end. Influenced by this consideration, I have been induced to select the non-metallic elements, or the zootic elements, as a modern writer has termed them, as the subject of the present lectures, because the metallic elements have been recently discussed in the other theatre by Mr. Mansfield, and chemistry, as applied to the industrial arts, by my colleague, Mr. Brande.

I do not propose to treat the subject in a purely chemical sense; to discuss the non-metallic elements in the order of their discovery; to pass under notice the various theories of which these elements have been the subjects, or even to make known all their minuter characteristics. My object is rather to treat of them broadly; to point out their more striking features; to consider them not only as chemical agents, but as fulfilling each its appointed function in the material universe. First, then, what do we mean by the term element? By it chemists understand, not a body incapable of subdivision into constituents,—for this assumption would imply a belief that the decomposing agencies of chemistry had already attained their finality,

—that we had reached the limits of decomposition,—that further progress in this direction would be impossible;—by the term element chemists understand any kind of matter which, up to the present time, has never *been* decomposed into constituents: hence such matter is considered to be an element provisionally, and subject to future modification. Of these elements we are at this time acquainted with sixty-two or sixty-three, of which the names are given in a diagram:—

Aluminium.
Antimony.
Arsenic.
Barium.
Bismuth.
† Boron.
† Bromine.
Cadmium.
Calcium.
† Carbon.
Cerium.
† Chlorine.
Chromium.
Cobalt.
Copper.
Didymium.
Donarium. (?)
Erbium.
† Fluorine.
Glucinium.
Gold.
† Hydrogen.
† Iodine.
Iridium.
Iron.
Lanthanium.
Lead.
Lithium.
Magnesium.
Manganese.
Mercury.
Molybdenum.
Nickel.
Niobium.
† Nitrogen.
Norium.
Osmium.
† Oxygen.
Palladium.
Pelopium.
† Phosphorus.
Platinum.
Potash.
Rhodium.
Ruthenium.
Scheelium.
† Selenium.
† Silicon.
Silver.
Sodium.
Strontium.
† Sulphur.
Tantalium.
Tellurium.
Terbium.
Thorium.
Tin.
Titanium.
Uranium.
Vanadium.
Yttrium.
Zinc.
Zirconium.

In this list the non-metallic elements are indicated by a cross, from which indication it will be seen that the metallic elements constitute a large majority of the whole, only thirteen out of the sixty-three being non-metallic; and from within the limits of this narrow range of only sixty-three has Omnipotence selected the materials which compose our globe, and the living beings which inhabit it. Out of these all the diversified forms and beings of the world are made. From the dense masses of rocks and mountains amongst inanimate things, to the fleeting atmosphere which surrounds us:—from the simpler forms of animal or vegetable life to the most highly organised, however different one from another in aspect or in functions,—they have all been created out of these elements in the list of sixty-three. Nor is this all. By a wonderful power of adaptation, which bespeaks Omnipotence, our earth and its inhabitants are not made up of these sixty-three bodies equally distributed, but by far the greatest portion of terrestrial matter is composed of the thirteen non-metallic elements; and yet more strange, it will presently be demonstrated that between two-thirds of the whole material terrestrial universe, organic and inorganic, are composed of one alone of these non-metallic simple elements, OXYGEN. How great, then, must be the power of adaptation imposed on these elements, by which they are made to discharge so many functions, and to appear under so many different forms!

The term non-metallic is one, as its name signifies, of exclusion, being founded on a previous appreciation of the term metallic. Hence the general properties of metals should be glanced at in this course. All the more common members of the metallic group possess certain external qualities, which create, we scarcely know why, an appreciation of their nature, and bespeak for them the denomination of *metals*, as being consistent with certain preconceived notions we had formed of them. Nevertheless it is difficult, perhaps impossible, to specify the exact nature of a metal by associating it with any one unvarying set of qualities. Thus, although great specific gravity is a characteristic of most metals, potassium and sodium are so light that they swim in water. A certain lustre, termed metallic, is also another leading quality of metals; but this is also participated by the non-metallic body, iodine, and is absent in certain metals. Opacity, again, is an almost universal characteristic of metals, as we see them; but gold has been beaten into leaves so fine * as to become partially transparent,—not in consequence of any cracks, holes, or fissures, but by the shining of light through its substance. This phenomenon renders the supposition probable that other metals might also become transparent, provided they were sufficiently malleable to be beaten out into leaves of the necessary fineness; and thus we are obliged to relinquish the idea of opacity as being necessarily a quality of metallic bodies.

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* One two hundred thousandth of an inch in thickness. The light transmitted is green, although the incident ray was white; thus negativing the supposition of a mere passage through orifices in the gold, and proving the metal to possess a true refractive power,—unequal for different colours of light, as is the case with most transparent media. Silver leaf only one hundred thousandth of an inch in thickness is perfectly opaque.

Power of conducting electricity is another general quality of metals; but it cannot be said to characterise this class absolutely, seeing that it is also participated by certain non-metallic elements. Although not universal for all metals, the three qualities mentioned,—that is to say, great specific gravity, peculiar lustre, and facility of conducting electricity,—are the most general. Amongst the less general qualities of metals are, malleability, or power of extension under the hammer,—ductility, or the property of being drawn out into wires,—brittleness, or hardness:—properties which belong to certain classes of metals, and not to others; thus enabling us to arrange them in groups. Although then it be not possible to define with logical precision the term metal, yet the possession or the absence of certain qualities has sufficed to fix with sufficient exactness the limits between the metallic and the non-metallic in our list of sixty-two or sixty-three elementary bodies.

TABLE OF METALS KNOWN TO THE ANCIENTS.*

Gold	was	the Sun	and was thus represented	☉
Silver	,,	,, Moon	,, ,, ,, ,,	☽
Mercury	,,	Mercury	,, ,, ,, ,,	☿
Copper	,,	Venus	,, ,, ,, ,,	♀
Iron	,,	Mars	,, ,, ,, ,,	♂
Tin	,,	Jupiter	,, ,, ,, ,,	♃
Lead	,,	Saturn	,, ,, ,, ,,	♄

TABLE OF THE SPECIFIC GRAVITY OF METALS.

Platinum	20.98
Gold	19.258
Iridium	18.680
Tungsten	17.50
Mercury	13.568
Palladium	11.50
Lead	11.35
Silver	10.47
Bismuth	9.80
Uranium	9.00
Copper	8.89
Cadmium	8.60
Cobalt	8.53
Nickel	8.27
Iron	7.78
Molybdenum	7.40
Tin	7.30
Zinc	7.00
Manganese	6.85
Antimony	6.70
Tellurium	6.10
Arsenic	5.8
Titanium	5.3
Sodium	0.972
Potassium	0.865

TABLE OF THE MALLEABLE METALS.

Gold.
Silver.
Copper.
Tin
Cadmium.
Platinum.
Lead.
Zinc.
Iron.
Nickel
Palladium.
Potassium.
Sodium.
Frozen Mercury.

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[*] The ancients designated them by the names of the planets to which they were supposed to have some mysterious relation; and each was denoted by a particular symbol, representing both the metal and the planet. This planetary designation was adopted by the alchemists, and forms the basis of some chemical and medical terms now in use. Thus we have "Lunar caustic," or fused nitrate of silver; "Martial pyrites" of native sulphuret of iron; "Mercury" is even now as much a term as quicksilver; and "Saturnine paralysis" is paralysis caused by salts of lead.

TABLE OF THE FUSIBILITY OF METALS.*

		Fahrenheit.	
Fusible below a red heat.	Mercury	—39°	Different Chemists.
	Potassium	136°	Gay, Lussac, and Thenard.
	Sodium	190°	
	Tin	442°	Crichton.
	Bismuth	497°	
	Lead	612°	
	Tellurium, rather less fusible than lead		Klaproth.
	Arsenic, undetermined.		
	Zinc	773°	Daniell.
	Antimony, little below redness.		
	Cadmium	442°	Stromeyer.
Infusible below a red heat.	Silver	1873°	Daniell.
	Copper	1996°	
	Gold	2016°	
	Cobalt, rather less fusible than iron.		
	Iron cast.		
	Iron malleable		require the highest heat of a smith's forge.
	Manganese		
	Nickel, nearly the same as cobalt.		
	Palladium.		
	Molybdenum		Almost infusible, and not to be procured in buttons by the heat of a smith's forge, but fusible before the oxy-hydrogen blowpipe.
	Uranium		
	Tungsten		
	Chromium		
	Titanium		
	Cerium		
	Osmium		
	Iridium		
	Rhodium		
	Platinum		
	Columbium		

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* Turner.

TABLE OF THE DUCTILE METALS ARRANGED IN THE ORDER OF THEIR DUCTILITY.

Gold.	Iron.	Tin.	Palladium.
Silver.	Copper.	Lead.	Cadmium.
Platinum.	Zinc.	Nickel.	

TABLE OF THE ACTION OF SULPHURETTED HYDROGEN (HYDROSULPHURIC ACID) AND HYDROSULPHURET OF AMMONIA ON THE CALCIGENOUS * METALS. (BRANDE.)

Metal.	Solution.	Sulphuretted hydrogen.	Hydrosulphuret of ammonia.
Manganese	Neutral protochloride . .	No precipitate .	Copious ochre yellow.
Iron . .	Neutral protosulphate . .	Blackish, & small in quantity .	Black and abundant.
Ditto . .	Perchloride . .	Abundant black .	Black.
Zinc . .	Chloride . . .	A little opalescent then milky . .	Straw-colour and copious.
Tin. . .	Acid protochloride	Brown . . .	Deep orange.

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* Metals admit of division into three primary classes, viz., kaligenous, terrigenous, and calcigenous—the distinction between which is founded upon the different qualities of metallic oxide. Metals, which by combination with oxygen form alkalies, are termed kaligenous, and are potassium, sodium, and lithium. Those which by combination with the same form earths, are termed terrigenous, and are calcium, forming lime; barium, and strontium, forming respectively baryta and strontia. Magnesium, aluminium, yttrium, thorium, glucinium, cerium, lanthanium, didymium, zirconium; all the remaining metals, form neither alkalis nor earths by union with oxygen, but generate substances which early chemical authors termed *calces*. Hence the term calcigenous. Calcigenous metals are alone affected by hydrosulphuric acid and hydrosulphate of ammonia.

TABLE—(*Continued.*)

Metal.	Solution.	Sulphuretted hydrogen.	Hydrosulphuret of ammonia.
Tin . . .	Acid perchloride	At first 0, then yellow & copious	Apple-green.
Cadmium.	Chloride . . .	Yellow	Yellow.
Copper .	Protochloride .	Deep brown . .	Brown.
Ditto . .	Nitrate . . .	Black	Brown and black.
Lead . .	Chloride and nitrate . . .	Ditto	Ditto.
Antimony	Tartrate of antimony and potassa	Deep orange-red	Bright orange.
Bismuth .	Tartrate of bismuth and potassa	Deep brown . .	Deep brown.
Cobalt .	Chloride . . .	0 but blackish .	Copious black
Uranium .	Sulphate . . .	Brown	Blackish brown.
Titanium.	Acid chloride .	0	Black.
Ditto . .	Neutral sulphate	0	Green.
Cerium .	Protosalts . .	0	White.
Tellurium	Sulphate . . .	Black	Black.
Arsenic .	Arsenious acid.	Yellow . . .	Yellow.
Ditto . .	Arsenic acid .	Ditto . . .	Ditto.
Nickel. .	Sulphate . . .	Brown	Black.
Mercury .	Acid nitrate .	Black, then grey, then black by excess of test . .	Black by excess of test.
Ditto . .	Acid pernitrate	Ditto	Ditto.
Ditto . .	Corrosive sublimate . . .	Brown by excess of test	Ditto.
Osmium .	Solution of oxide	Metallic . . .	Metallic.
Palladium	Chloride . . .	Brown	Brown.
Silver . .	Nitrate . . .	Black & metallic	Ditto.
Gold . .	Chloride . . .	Black and reduced gold . .	Yellow.
Platinum.	Ditto	Deep brown . .	Pale Brown.

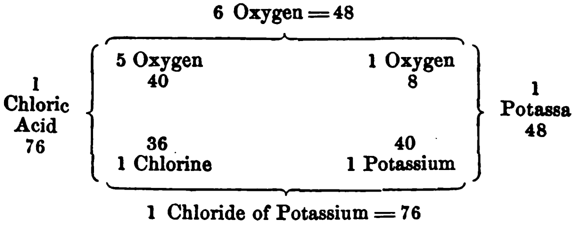
As the non-metallic elements constitute so large a portion of the material world, entering into such numerous forms, appearing under such protean aspects, ministering to purposes so dissimilar and opposed, it is evident they must be endowed with wonderful adaptive powers. These powers are manifested in various ways; their study constitutes an interesting portion of chemical science, and displays some of its most interesting phenomena. But higher contemplations than those of mere chemical science are suggested by the investigation of these properties; objects of greater interest present themselves than the deduction of laws or the perfection of systems. An investigation of the distinctive properties of chemical elements unfolds to us the mysterious yet simple means chosen by the Omnipotent for accomplishing his results; teaching us how elements the most seemingly unmanageable and disaccordant are made to watch like ministering angels around us,—each performing tranquilly its destined function,—moving through all the varying phases of decomposition, decay, and death,—then springing into new life, assuming new forms, resting in passive inactivity, or assuming the extreme of violence, accordingly as either may be suited to accomplish the appointed end!

This adaptation of the elements to their various functions is accomplished by various means, some of which it will be my object to describe. The susceptibility of elements to change their form and their powers by combination is universal. It constitutes one of the most striking features of chemistry, and displays some of the most remarkable phenomena of the science. But in addition to the changes of composition and decomposition, there is yet another means by which the functions of bodies are altered. It is one altogether of recent discovery, and termed "*allotropism,*"—a property which embarrasses many of our previous conclusions as to what were supposed to be the fundamental laws of chemistry. Allotropism is the term employed to signify the existence of the same body under more than one form. It is therefore altogether different from the change effected by composition or decomposition: for on the assumption of either of these we should not be dealing with the same body but another,—the result of composition or decomposition, as the case might be.

Without enumerating all the distinctive characters which separate each metallic element from its associate, a mode of treatment which would be adopted in a systematic course of chemistry, it will be my object, as I have already announced, to treat the subject in a different way. Amidst a multitude of characteristics possessed by an element, there are some which stand forth in prominence beyond the rest, which more than others strike an observer, impressing themselves forcibly on the mind, creating a physiognomy, if the term may be permitted, for each individual element. To these salient characteristics, or points, I purpose especially to direct your attention; and, commencing with oxygen, the chief subjects for contemplation, the chief distinctive points of that element for discussion, will be—firstly, its enormous distribution throughout nature; secondly, its existence under a quiescent form; thirdly, its condition of intense activity; and, fourthly, the mysterious allotropic change of qualities it assumes under the condition which has been termed by M. Schönbein, of Bâle, its discoverer, "*ozone.*"

Having prefaced these remarks, let us now proceed to develope and collect some of the first elementary non-metallic substance which falls under our notice—oxygen. There are various ways of obtaining it; but the most convenient under present circumstances, and the one therefore that I shall follow, consists in applying heat to a glass retort containing a mixture of equal parts black oxide of manganese and chlorate of potash. The black oxide of manganese unmixed would liberate oxygen at a higher temperature, but in that case we could no longer use a retort of glass, but must employ an iron retort and the heat of a furnace. Chlorate of potash alone would also yield oxygen, and a glass retort might be used; but the heat required is uncomfortably high, and the gas is not evolved with great facility.

Under the present conditions of heat and mixture, it is the chlorate of potash alone which yields up its oxygen; therefore, in framing a diagrammatic explanation of what takes place, the black oxide of manganese may be omitted. The salt chlorate of potash is very rich in oxygen,—every hundred and twenty-four parts of it by weight containing forty-eight parts of this element, united in the solid form with thirty-six parts of chlorine, and forty of the metal potassium. On the application of heat, all this oxygen is driven off in the gaseous state, and chlorine united with potassium, forming the chloride of potassium, remains.



Having now developed this element oxygen, and collected several jars of it by means of the well-known pneumatic trough, let us proceed to examine some of its most striking qualities. We need not yet call in the aid of experiment for demonstrating many of these. Let us contemplate it as it there exists, and ponder on the change of quality it has there assumed. Whilst locked up in the solid body from which we have obtained it, how different must have been its qualities from those it now possesses: how altered its form. *There* itself was solid, here we have it as a gas; and so persistently, so obstinately does it maintain its gaseous state, that no amount of pressure hitherto applied has been sufficient to change even into the liquid form that half-way resting-place towards the solid state. This consideration enables us to form some appreciation of the enormous force which must have been operating to have maintained it pent up there. In some cases gaseous bodies have been condensed by pressure into the liquid form; and one gas (carbonic acid) has been condensed by pressure and low temperature acting conjointly into a solid; but every attempt of this kind hitherto made in the case of oxygen, has failed. Continuing to regard this apparently empty space, but which, in reality, is filled with oxygen, remark that the gas is colourless—invisible. Personal observation, moreover, will satisfy you that it is alike devoid of taste and smell. Judging from this casual evidence, therefore, oxygen, in the state of gas, is devoid of every marked property—any energetic action. It appears to be altogether passive, incapable of manifesting any strong force of whatever kind. This would be the idea entertained by a common observer,—this might have been the opinion formed of it even by a chemist, arrived only at our present stage in the investigation of gaseous oxygen. Yet no substance possesses a wider range of affinities, manifests more numerous or a greater variety of powers, assumes a greater number of marked aspects, and comes before us in a greater number of forms—than oxygen. After noticing the obvious qualities possessed by oxygen gas,—of colourless transparency, want of taste, and want of odour,—the next quality to be indicated (not quite so obvious as the preceding, though easily demonstrable) is its weight. One hundred cubic inches of this gas, at 60° F. and 30 in. Bar. (concerning the bulk of which you may form some idea by seeing that quantity measured out in a jar), weigh thirty-four grains six-tenths, whereas an equal bulk of atmospheric air weighs 31,0117 : hence, oxygen gas is heavier than the atmosphere, in the ratio of 1.111 to 1, or, in other words, oxygen gas is one and one-tenth, and a little more, heavier than atmospheric air :—

OXYGEN—ITS ABSOLUTE AND COMPARATIVE WEIGHT.

100 C: I: weigh . . .	34·60 gr.
To Air	1·111
Hydrogen	16·

The method of ascertaining the weight of oxygen or any other gas is exceedingly simple in theory, but its practice requires some delicate manipulation. In the first place, a large bulb, or flask, is taken and weighed when in its ordinary state or filled with atmospheric air· The vessel being now attached by convenient mountings to the plate of an air-pump, the air is exhausted, and a vacuum produced. Being weighed again in its exhausted condition—that is, without its aërial contents—the loss of weight corresponds with its volume of atmospheric air. The flask being now attached to the vessel containing the gas, the connecting stop-cock is opened and the gas rushes in. The flask is now again weighed, and the difference between its present and former weight indicates how much the gas is heavier or lighter than atmospheric air. In performing this operation, both atmospheric air and gas must be deprived of moisture, which is accomplished by passing them through a tube containing fused chloride of calcium,—a substance having a great avidity for water. It is necessary, also, that great attention be paid both to the temperature at which the estimation takes place and to the external atmospheric pressure as indicated by the barometer. When possible, the operation should be conducted when the barometric column stands at 30 inches, and the thermometer is at 60° F.; such being the conditions under which such estimations are always assumed to take place. If the weighing operation, however, be conducted at any other temperature and pressure, the results may be reduced to their equivalent at 60° F., and 30 inches by a simple calculation.

Let us now proceed to see how we could discover the presence of oxygen in the state of gas—how we could individualise it from other gases of similar physical aspect. Its ordinary appearance will not aid us in accomplishing this, therefore the assistance of experiment must be called in. If I take this jar of colourless gas—no matter what it is called—and, passing the jar which contains it under the water of a pneumatic trough, invert the jar and liberate its contents into another jar containing oxygen, an orange-red colour results, and the gaseous volume which before this treatment remained of permanent bulk when in contact with water, now becomes diminished by absorption. No known gas, save oxygen, or a gaseous mixture containing it, will effect this change: hence it follows that the gas in question becomes a specific test for oxygen.*

Thus we possess a ready means of discovering the presence of oxygen in the state of gas; and repeating the experiment with the substitution of atmospheric air for pure unmixed oxygen gas, we observe a similar effect. Hence, in point of fact, we effect the analysis of atmospheric air by this means; for all the oxygen which it contains having entered by combination into these orange fumes, the latter become absorbed by the water; thus leaving nitrogen the second constituent of the atmosphere alone, which, not being capable of absorption by water, remains behind.

[This absorption of oxygen on the addition of binoxide of nitrogen is dependent upon the formation of hyponitrous, nitrous, and nitric acids, and was applied by Dr. Priestley to endiometrical purposes, *i. e.* the analysis of the atmosphere. His rule being to throw into a limited volume of atmospheric air binoxide of nitrogen so long as colouration took place, and aqueous absorption ensued. He then divided the total amount of absorption by four, which should give the amount of oxygen. But there are objections to the plan, of the existence of which Priestley was not aware. These objections will be seen after a consideration of the composition by volume of binoxide of nitrogen, hyponitrous, nitrous, and nitric acids.

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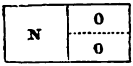
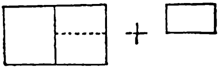
* The gas used in this testing operation is the binoxide, or deutoxide of nitrogen—nitric oxide, as it is sometimes called. The rationale of the action resulting, as well as its endiometric application, and the objections to the latter, will be detailed in another place.

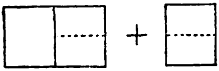
Let the binoxide of nitrogen be thus indicated:—



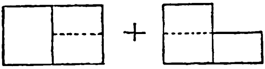
; then,



= Hyponitrous Acid;



= Nitrous Acid;



= Nitric Acid.

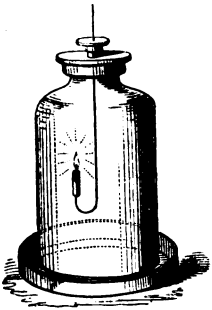
The relative quantities of these substances are liable to variation, for which reason it is evident that the rate of diminution of the mixture must vary also. The circumstances modifying these combinations are, (1) diameter of tube; (2) degree of agitation; (3) rapidity of mixture; (4) relative proportion of gases; (5) opposite conditions of mixing them.

The rationale of ascertaining the amount of oxygen absorbed by dividing the total amount of absorption by four, is based upon the supposition, as already noticed, that hyponitrous acid alone is formed, and is thus explained:—Every volume of binoxide of nitrogen requires the fourth of a volume of oxygen to convert it into hyponitrous acid; hence one fourth of the total absorption is equal to the volume of oxygen which has entered into combination, and caused the change of binoxide of nitrogen into hyponitrous acid.]

The operation of this test-gas, then, has demonstrated the presence of gaseous oxygen in the atmosphere, of which it is a constituent in the ratio of 20 to 100 parts by measure, the remaining 100 being nitrogen; if we except a very minute portion, about one part in every thousand of carbonic acid gas. Consider how bland, and seemingly inactive is oxygen gas as it exists in the atmosphere. Consider how it pervades, unseen, almost unthought of, the delicate air passages of our lungs, and surrounds our bodies unharmed. Consider it in relation to the tender organism of living things. Reflect on its necessity to life. Picture to yourselves the desolate waste of our globe without its atmosphere. How all-important is the atmosphere, how manifold its functions, yet how tranquilly does it perform them, how seemingly devoid of all energy, how passive its constituents!

The quiescent, passive state of oxygen, which we have seen to characterise it when in a gaseous form, both uncombined and as a constituent of atmospheric air is not dependent upon the condition of gas. In water it exists as a liquid, yet how weak, how devoid of all violent energies is water! Oxygen exists most widely diffused in a solid form in many of our most common minerals and rocks. Silica, or flint, contains about half its weight of oxygen, lime contains two-fifths, alumina one-third. What seemingly powerless, inactive bodies are all these! how apparently endowed with no strong chemical energies. Yet, of this piece of rock crystal, one half its entire weight is oxygen! Thus have we seen this non-metallic element capable of assuming, whether under the gaseous, liquid, or solid condition, a state of the most complete inactivity; retaining all its forces, however, under a marked aspect, and capable of exerting them with violence under conditions which will presently be observed. This inactivity is one extremity of the scale of qualities possessed by oxygen. Intense violence is another, examples of which I shall soon proceed to show.

But there is a third condition oxygen may assume, intermediate between the two; a condition which we may term the *allotropic* or ozonized, and the explanation of which is, as I before remarked, one of the especial points connected with oxygen to which I purpose drawing your attention in the present lecture. It will be convenient, however, to discuss the extremes first, and afterwards interpose the mean; therefore, let us proceed to develop the active state of oxygen. First, then, as regards the activity which oxygen in its gaseous and uncombined state is capable of assuming,—(for its activity may also be demonstrated when reduced by combination to a liquid or a solid form,)—as regards its activity in the uncombined and gaseous state, I shall find it necessary to go through a set of experiments, all perfectly well known to you doubtless, but which, being essential to the treatment of the subject under consideration could not with propriety be omitted here.



In the first place, I immerse in a jar of oxygen a burning taper, when you observe a very different result takes place to what would have happened in atmospheric air — the combustion proceeds more rapidly and with greater splendour. I now repeat the experiment with this difference: instead of immersing the taper whilst flaming, I put out the flames and only immerse the ignited wick. The result of this is to cause the flame to reappear, and to continue with splendour as before.

[In this and similar experiments one plan of manipulation is required. The jar designed to be employed for containing the gas to be experimented upon, is first carefully cleaned, dried, and warmed; the mouth, together with its ground stopper, is now carefully examined, for the purpose of ascertaining whether the ground joint be accurate. This may be accomplished by rubbing both stopper and ground surface of the jar's mouth with a little pomatum, replacing the stopper, filling the jar with water in the pneumatic trough, and sliding it on the shelf of the latter. Here, being left for the space of ten minutes, it will readily be seen whether the ground juncture be tight or the contrary, by observing whether the jar still remains full of water, or whether the water sinks.

If the jar be found trustworthy, it is filled with gas in the usual manner, and, being filled, is slid aside on a flat dish. A common dinner-plate answers very well for this purpose. In effecting this sliding operation, care must be taken that the stopper of the jar do not get forced out by the upward pressure of the gas, temporarily condensed by the action of sliding, and slightly depressing the jar in the pneumatic trough. It is well therefore to exert, by means of the finger, slight pressure on the stopper during the act of sliding; a precaution more especially requisite when, instead of a ground glass stopper, the jar is occluded by means of a flat glass plate, ground and accurately laid horizontally upon the orifice of the jar—the circumference of this orifice being accurately ground for the purpose.

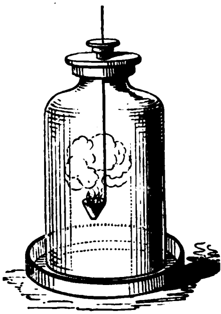
The jar being filled ready for displaying combustive agencies, the manipulative details necessary to be remembered for manifesting them are as follows. Whatever may be the kind of combustion to be developed—whether that of a taper, as in the present instance, or of phosphorus, sulphur, &c., placed in a small copper ladle—the one general remark applies of occluding the mouth of the jar with a flat metallic plate, not a cork. Philosophical instrument makers are in the habit of manufacturing plates, or discs, of the kind indicated;

through the centre of which accurately slides the metallic stem, on the extremity of which the substance to be burned is hung. A far simpler form of device, however, answers equally well. Having procured a round disc of copper, tin plate, or zinc, and made a hole in its centre, large enough to admit the wire intended to support the substance to be burned, pass the wire through it, and then *tightly* through a cork. By this arrangement the cork merely serves as a pressure slide, regulating the depth to which the wire may want to be depressed; and the metallic disc alone effects the closure of the jar. As the operation of the metallic disc is only temporary, its surface need not be ground, as would have been the case had it been designed to secure the gas for any length of time.]

Instead of a taper I might have varied the experiment, by employing chips of wood, or any of the substances commonly known as combustible, when similar evidence would have been afforded of the tendency of oxygen gas to promote combustion. Simple though this experiment of a burning taper be, it nevertheless forms a subject of fruitful contemplation. Observe that the results of combustion of the taper and of the chips of wood are invisible. In common language, the combustible substances, might be said to be destroyed, so intangible have they become. Presently, we shall find examples of the results of combustion being fixed solids; but such is not the case with any of the ordinary combustible bodies. Consider the beneficence of this provision,—consider what would have been the consequences if the results of ordinary combustion had been different to what they are,—had they been solid bodies, instead of gases and vapours.

Proceeding with our demonstration of the activity of gaseous oxygen when developed by heat, and evidenced in the process of combustion,—I will take now a piece of charcoal, fastened to wire, and igniting it by the blowpipe flame, I will immerse it in another jar of oxygen. Combustion of the charcoal proceeds with great rapidity —scintillations fly off in all directions,—and, if we wait long enough, and if the charcoal be not too large for the volume of gas, all the charcoal will disappear,—will have been destroyed, to use an expression of ordinary language; but in the language of chemistry will have become converted into an invisible product.

And now, with regard to demonstrating the existence of this new product of combustion, we may effect it in various ways. If I take the jar in which the charcoal has been burned, and by means of the pneumatic trough transfer its contents to various bottles, their contents may be tested, and demonstration of the existence of a result of combustion acquired. Into one of these bottles I immerse a moistened slip of litmus paper, which immediately turns red, a change not affected by atmospheric air. Into another bottle, plunging an ignited taper, it is immediately extinguished;—and into a third I pour some lime-water, which on being agitated turns white, as though it were pervaded (which indeed is the fact) with chalk. All these results are evidenced, but to a less marked degree in the oxygen, which has been the medium of supporting the combustion of slips of wood and the taper: less marked, because the combustive elements here are not carbon alone, which generates carbonic acid, reddening litmus paper, and turning lime-water into chalk,—but also hydrogen, which by combination with oxygen forms water.



Varying the material to be consumed, I now take a piece of sulphur, and having put it into a little copper dish attached to a wire—I ignite it, and plunge it into another jar of oxygen. As in our preceding experiments, combustion of extreme intensity takes place, the sulphur disappears,—a sort of vapour surrounds it,—disappears also after a time; and now, on examining the water in the bottom of the jar, I find it endowed with not only the property of reddening litmus, but it is distinctly sour to the taste, and, if added to an infusion of red rose petals, the infusion changes to white, or is bleached.

The intense energies capable of being manifested by oxygen, when in the gaseous state, under the circumstances necessary to bring them into play, have been well manifested by the preceding experiments. Nor is this quality limited to oxygen in the gaseous state alone.

In the condition of liquid and solid combinations of many kinds, its latent energies can be evolved, although they lie more dormant, so to speak, and are more difficult to be brought into action, than in gaseous oxygen. The action of the metal potassium on water beautifully illustrates the power of oxygen called forth from one of its liquid combinations.

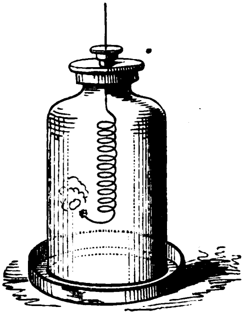
Were I to take any of the ordinary combustible bodies, and plunge them into water, there would result —as I need not explain—no combustion. Hence, water has come to be regarded as in its essence the antagonist to combustion, but how incorrectly the chemist is aware. Every nine parts by weight of water contains eight parts by weight of oxygen,—and oxygen being the most powerful of all supporters of combustion, it should seem that water ought to favour the combustive operation, provided only a sufficiently energetic play of affinities could be brought into operation. This, indeed, is true:—for if I project a globule of potassium into a vessel of water, the play of resulting affinities is so strong, that oxygen is abstracted from the water, and the potassium takes fire. It is strange at first sight,—though perfectly accordant with other analogies when examined, and admitting of an easy explanation,—that potassium, reversing the apparent order of things, is greatly more combustible in water than in gaseous oxygen. To demonstrate this fact, I take another globule of potassium, and putting it into a copper ladle, I direct upon it the flame of the spirit lamp, until it takes fire, and now plunge it into a vessel of oxygen gas. At first, and for a very short period, it burns: now, however, it ceases to burn, and you will observe it to be coated with a shiny white coat. This coating is of potash—the result of the combination of potassium with oxygen, and its presence imposes a limit to the combustive agency, by protecting the underlying potassium from the contact of the gas. Had the substance potash been volatile—had it been soluble in oxygen gas, or atmospheric air, then we should have had conditions similar to those involved in the combustion of a taper, a chip of wood, or a piece of charcoal; but because that it is non-volatile, insoluble in air and oxygen, combustion ceases from the cause specified. Potash, however, is soluble in water, hence, it is removed as soon as formed upon the surface of the potassium, and the play of affinities being exceedingly strong, the combustive agency proceeds without interruption. Under the head of carbon, I shall have to draw attention more in detail to the conditions limiting the combustion of potassium in atmospheric air, in tracing the consequences which would have followed had the ordinary combustible substances, carbon especially, been like potassium, subjected to the law of forming, by combustion, a result solid, or insoluble in atmospheric air.

Let us now examine the portion of water in which the potassium has been burned. It contains potash dissolved, as may not only be demonstrated by the taste, but by the operation of tests. Thus it tinges yellow turmeric paper brown—it changes litmus paper, reddened by acid fumes, back to its original colour—both characteristics demonstrative of the presence of an alkali. If heat be applied all the water may be driven off, leaving the alkaline residuum behind; thus characterising the presence of a fixed or non-volatile alkali; and appropriate tests demonstrate the alkali to be potash.

Reflect on the nature of the agency, and the result. Not only have we a demonstration of the stupendous power which lay dormant in the liquid oxygen; but we have also demonstrated its power of generating the most opposite results. When we burned charcoal and sulphur in oxygen, there resulted an acid; we now have an alkali, a substance the very reverse of an acid in every chemical function; yet oxygen has a capability of so metamorphosing its *kind* of force that it forms both acids and alkalies.

I shall now select two other cases of combustive energy due to the agency of gaseous oxygen; both perfectly well known to you, doubtless, but which, inasmuch as they relate to the subject on which we are engaged, could not well be omitted here. The first case is that of the combustion of iron wire in oxygen gas, an experiment originating with the illustrious Priestley, to whom the science of pneumatic chemistry is so much indebted.

If a piece of iron, or by preference *steel* wire, be formed into a helix attached to a metallic disc at one extremity, and armed with a small chip of wood, or the extremity of a brimstone match, at the other; if now the match or chip be ignited, and the helix plunged into a jar of oxygen gas, combustion proceeds with great energy until the wire is altogether consumed. This experiment has now become perfectly familiar to every one—it will therefore be denominated trite and commonplace by some—its mere indication might be thought sufficient. I cannot bring myself to call any phenomenon trite, commonplace, unworthy of repetition, which displays the action of such glorious forces; which illustrates such all important bearings as does this combustion of iron wire in oxygen. It is intimately associated, moreover, with a memorable epoch in the annals of chemical theory—the overthrow of the phlogistic doctrine of combustion. The process of combustion was assumed by Bergmann and Stahl, to be due to the evolution of an imaginary agent, termed by them *phlogiston.* Thus a loss was assumed to occur to every substance which was submitted to the combustive agency; and the theory seemed not disaccordant with the greater number of the products of combustion. When we burn a candle, or wood, or a piece of charcoal, or sulphur, in oxygen gas or in atmospheric



air, a loss does seem to be the result; simply because the results of combustion, in these cases, are either gases or vapours, of which the existence, not being apparent to common observation, requires to be made known by experiment. In this operation of burning iron wire, however, the result of combustion is a solid; and if we were to weigh it we should find it to be heavier than the original weight of iron. If, proceeding farther, the exact amount of this increase of weight were determined, it would be discovered to be exactly equal to the weight of the oxygen gas absorbed during the combustion.*

Amongst all the combustible substances we have hitherto used for the purpose of demonstrating the activity of oxygen gas, when called into play by elevated temperature, sulphur is the most combustible; the others are characterised by no great natural violence of combustion, and iron would be described in common language as incombustible; nevertheless, the combustive agency has been in all cases extremely vivid. What then are we to anticipate if, instead of these moderately combustible bodies, another be employed which, even under the common circumstances of being surrounded with atmospheric air, is characterised by violence in this respect?—what if we employ phosphorus, a substance which takes fire at a temperature very slightly above that of the human body, and which cannot be subjected to moderate friction without bursting into violent flame? Why in this case we develope the maximum effects of combustive agency, and manifest under their glorious aspects of heat and light an exercise of those mighty forces brought into play by the operation.

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* An exposition of the phlogistic theory, and of experiments by which its fallacy was determined, has already been given.

The intense luminosity of phosphorus, when ignited in oxygen, is intimately connected with the theory of luminous combustion generally; and although a full exposition of this matter strictly belongs to the heads of carbon and of hydrogen, yet it would be injudicious to allow it to remain wholly unnoticed here.

[Now that the combustive operation has ceased, it may be observed that the jar is pervaded with white vapours; presently these vapours will subside, and become absorbed in the water. In using the term *vapour* here, we must qualify the word to mean the floating suspended particles of a solid not yet deposited. These particles are phosphoric acid, and it is to their presence that the intense luminosity of phosphorus burned in oxygen is due. Solid particles become incandescent, and therefore luminous at a temperature much lower than those of liquids or of gases; hence extreme luminosity is always the marked concomitant of the combustion of these bodies, which generate by burning either permanent or temporary solid particles. This is the case with phosphorus, and hence the great luminosity of its combustion; it is not the case with sulphur, and hence the extreme feebleness of the light evolved. As regards carbon, that great pabulum of combustion, that great source of artificial light and flame—the condition is altogether peculiar, and strikingly displays the all-wise forethought of a benevolent Creator. The final result of its combustion is a gas—the carbonic acid, and thus, having ministered to our wants, by evolving its light and heat, it is wafted away; but the most strange and wonderful provision is this:—before the final result is arrived at, the *gaseous* result, there exists an intermediate state of solidity, thus furnishing particles of a kind most capable of evolving light and heat. In this explanation I am, strictly speaking, anticipating the subject of a future lecture, namely, *Carbon*, but this place seemed appropriate for me to give a passing indication of the conditions subservient to luminosity.

[The operation of burning phosphorus in oxygen gas requires certain precautions, otherwise not only is the combustion jar liable to be broken, but the dispersion of liquid and burning phosphorus is attended with much danger. The combustion ladle should be deep, small enough to enter the combustion jar without contact on either side, and perfectly dry. The phosphorus also should be perfectly dry, having had all its moisture removed by contact, not friction, with a little bibulous paper. It should not project above the level of the sides of the deflagrating ladle, because during the act of violent combustion burning particles might disperse and stick against the sides of the jar, thus infallibly causing rupture of the glass. A similar result would be occasioned by employing wet phosphorus, the aqueous moisture from which, by expanding into steam, would scatter the melted phosphorus in all directions. One other point still remains to be attended to. The phosphorus, dried, and placed in the deflagrating ladle, should be ignited on the surface, by touching it with a hot wire, not by holding the whole ladle over a flame. These directions being attended to will ensure the success of the experiment, whereas, by neglecting them, simple though they may appear, or any one of them, failure of the experiment is certain, and extreme danger is imminent.]

Thus have we arrived at some appreciation, by means of these simple experiments, of the stupendous amount of force latent in oxygen. We have seen this force manifest itself under the aspects of light and heat; we have seen it form acids at one extremity of the scale of chemical actions; we have seen it form alkalies at the other. We have demonstrated this force to attach to oxygen not only in a gaseous condition, but to exist apparently unimpaired in the seemingly inert, powerless material, water. Were we to go through the long list of organised bodies which chemistry makes known to us, that same force, modified by combination, masked, disguised, would be discoverable in all. Abundant evidence is forthcoming therefore to illustrate the active state into which oxygen may be called from its gaseous and liquid conditions. In completing therefore our proposed sketch of oxygen in a state of activity, it only remains to advert to the remaining cohesive state which oxygen may assume, that is to say, as a constituent of certain solids. An examination of these readily demonstrates to us the truth that the force still exists, although the oxygen is combined with such various amounts of force in different combinations that the readiness with which it can be called into play is extremely various. In one of our most common mineral constituents, silica or flint, oxygen exists, as I have already stated, to the extent of one-half the entire weight of that substance; and here it is combined, imprisoned as it may be said, with such force that, notwithstanding its great quantity in small space, its powers are not readily manifested.

Other solid oxygenised bodies, however, there are in which the affinities are so nicely balanced, that a slight decomposing cause is sufficient to rend the elements, as we may say, from each other, and set the oxygen free. Of this a very beautiful instance is furnished by the chlorate of potassa—the substance from which the oxygen gas employed during the course of this lecture has been obtained. The operation of procuring oxygen gas from it shows us that heat suffices to overcome that admirably poised balance of affinities by which the whole is held together; but there are other means. For instance, if I take a little sulphur, or carbon, or phosphorus, or sulphuret of antimony, or, to generalize, any other substance greedy of oxygen, and if I mix either of these with a little chlorate of potash carefully on paper, and with the minimum of friction—if I now fold these mixtures severally up in pieces of paper, and expose them to a smart blow on an anvil with a hammer, explosions of various degrees of violence ensue. With phosphorus, the explosive violence is greatest, with charcoal, least; this variation being indicative of the respective tendency of these substances to combine with oxygen under the circumstances of the experiment.*

The substance gunpowder, again, offers a remarkable illustration of nicely balanced affinities, and the convenient state in which oxygen as a constituent of a solid compound is held, ready to spring into action when required. The substance gunpowder, its powers and its applications, might well of itself claim a lecture. Firstly, we should have to notice the well balanced affinities existing in it—not, like some explosive bodies, so loosely interwoven that the slightest mechanical force, the slightest elevation of temperature should suffice to cause its explosion, rendering it totally unmanageable, inapplicable either to the purposes of mining, of engineering, or of war: — but having its affinities safely interwoven — securely tranquil — yet ready to spring into action on the application of a definite amount of heat.*

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* The explosive mixture of chlorate of potash and sulphur was formerly employed in the manufacture of percussion caps for guns, but has long been disused in favour of fulminating mercury, on account of the corrosive agency manifested by it on the gun nipples, an agency from which the fulminating mercury is exempt. Hence have sprung into use the terms *corrosive* and *anticorrosive* percussion caps. The mixture of sulphuret of antimony and chlorate of potash is exploded with difficulty by percussion, requiring a heavy hammer and a smart blow. It is therefore employed in the manufacture of artillery percussion tubes, which are formed of two quills, one inserted at right angles into the other, and filled with a mixture of sulphuret of antimony and chlorate of potash. The proportions of ingredients are so adjusted that the tube requires for explosion the force generated by a heavy hammer, falling through such a space and with such a velocity as to strike the tube with a pressure of 18 pounds. This sluggishness of explosion is purposely given to the artillery-tubes in order that they may not detonate by exposure to casual blows.

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* It is common for those unacquainted with the laws of projectiles and of explosive compounds, to form exaggerated notions of increased projectile range by the employment of explosive compounds of greater power than gunpowder. The realisation of these hopes is impossible—for two reasons. In the first place, assuming the existence of guns indefinitely strong, and gunpowder indefinitely powerful—that is to say, capable of liberating the maximum of gas in the minimum of time,—yet the point soon arrives at which the repulsive agency of the atmosphere, balances the impulsive agency of the explosive compound. Beyond this point no increment of impulsive force would urge the projectile further, and it is a point considerably within the range of power that can be exercised by common gunpowder. In the second place, supposing the advantageous employment of stronger explosive substances than gunpowder possible or desirable, there would yet be a limit imposed to their employment in the strength of materials of which guns can be made. Practical experience has fully demonstrated that the largest piece of ordnance which can be cast perfect, sound and free from flaws, is the mortar of 13 inches diameter, and even this

Thus we have the two extremes before us in the scale of manifestations which oxygen may assume. We have it in its tranquil, passive, waiting state, as locked up in rock-crystal, flint, and clay; as constituting eight-ninths of the bland liquid water; and even in its uncombined gaseous condition until the application of some disposing

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weighs 5 tons.—(*Sir W. Congreve.*) The French, it will be remembered, constructed a mortar to be employed in the siege of Antwerp having a bore of no less than twenty inches diameter, but it burst on the ninth time of firing. The appended table shows the rapid ratio in which atmospheric resistance preponderates over propulsive force. Hence the parabolic theory of projectiles is totally false in its application to projectiles moving at high velocity:—

TABLE OF THE MOTIONS OF A TWENTY-FOUR POUND SHOT PROJECTED AT FORTY-FIVE DEGREES OF ELEVATION.

Velocity per Second.	Range in Vacuo.	Range in Air.	Range Corrected.	Height to which the ball rises.
Feet.	Yards.	Yards.	Yards.	Yards.
200	415	320	330	100
400	1,658	1,000	1,019	300
600	3,731	1,321	1,419	400
800	6,632	1,687	1,719	464
1,000	10,362	1,840	1,878	515
1,200	14,922	1,934	1,978	561
1,400	20,300	2,078	2,129	606
1,600	26,528	2,206	2,264	650
1,800	33,574	2,326	2,391	694
2,000	40,450	2,438	2,510	738
2,200	50,155	2,542	2,622	778
2,400	59,688	2,640	2,726	816
2,600	70,050	2,734	2,823	852
2,800	81,241	2,827	2,916	887
3,000	93,262	2,915	3,002	922
3,200	106,111	2,995	3,085	996

force:—this is one extreme. We have it again showing its tremendous energies in the phenemena of combustion, rushing with violence into other forms—displaying the most glorious manifestations of light and heat—generating combinations of characters diametrically opposed;

COMPOSITION OF VARIOUS GUNPOWDERS.— FINE SHOOTING POWDER.

	Atoms.	Theory per Cent.	Practice per Cent.	Results of Combustion	Atoms.
4 Nitre	408	77·71	78	3 Sulphuret of Potassium ..	168
3 Sulphur	48	9·14	10	1 Carbonate of Potash	70
11½ Carbon	69	13·14	12	4 Nitrogen ...... 10½ Carbonic acid..	58 231
Total	525	99·99	100	Total	525

COMMON SHOOTING POWDER.

	Atoms.	Theory per Cent.	Practice per Cent.	Results of Combustion	Atoms.
1 Nitre	102	75	75	Sulphuret of Potassium	56
1 Sulphur	16	11·76	12·5	1 Nitrogen	14
3 Carbon	18	13·23	12·5	3 Carbonic Acid ..	66
Total	136	99·99	100·0	Total	136

MINERS' POWDER.

	Atoms.	Theory per Cent.	Practice per Cent.	Results of Combustion.	Atoms.
1 Nitre........	102	63·35	65	1 Bisulphuret of Potassium ..	12
2 Sulphur	32	19·87	20	1 Nitrogen........	14
4½ Carbon	27	16·78	15	1½ Carbonic Acid.. 3 Carbonic Oxide..	33 42
Total	161	100·00	100	Total	101

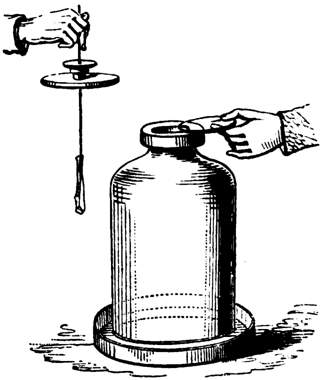
from the extreme of alkalinity on the one hand, to the most violent acidity on the other:—and, finally having gone through its metamorphic phases, assuming its appointed place of rest in the world's economy. But though extraordinary as are these glorious manifestations of power displayed by oxygen in its active state,—beautiful to view—admirable in their results,—there is yet another state it may assume more extraordinary still;—a state in which it is neither fully active nor fully passive, but intermediate between the two; a state in which the activity possessed is not only less in amount but different in quality. This is a state which may be designated as the semi-active or *ozonised* condition, and the discovery of which, as well as the chief investigations which have been made respecting it is due to the sagacity of M. Schönbein of Bâle.

Before entering upon the investigation of *ozone,* or *ozonised oxygen,* and showing its distinctive qualities, let us introduce it by a slight historical sketch.

Those who have operated with an electric-machine will not have failed to notice the peculiar smell which occurs in an apartment where the machine is in action. This has been denominated *the electric smell,* and it presents a marvellous field for philosophic contemplation. What is this smell? Does it depend on the presence of a substance formed? Does it depend on a substance modified? Such are the two questions which first present themselves for consideration. Numerous secondary questions then rise involuntarily up for solution in the mind of a thinking philosopher. Is the smell consistent with any other manifestation? Yes; for, if a piece of paper be moistened with a solution of starch and iodide of potassium, the paper is tinged blue. Now, this tinging blue is an indication of the liberation of iodine; and this liberation of iodine is an indication of the agency of oxygen; hence, thus far has been established a connection between oxygen in an active condition and—the electric smell.

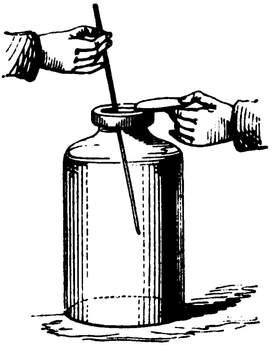
It remained for Professor Schönbein, of Bâle, to develope the germ of knowledge conveyed by the electric smell;—to expand and generalise it; to show that the same smell and its corresponding agency might be generated at pleasure, by various means, which it is the object of this lecture to set forth; to demonstrate other properties besides that of acting on the test-paper described; to render manifest qualities of bleaching, of intense oxidation, of deodorisation; to show that the agent on which all this depends is constantly generated in the stupendous laboratory of the physical world; and, lastly, to prove that the mysterious gaseous agency is neither more nor less than oxygen—oxygen gas existing in an allotropic form! Oxygen gas, that is to say, under a masked aspect. At least the present state of our knowledge warrants us in saying no more than this: but the philosopher, once led into this train of speculation, ends involuntarily by asking himself the questions—in what does chemical identity consist? in what will these wonderful developments of allotropism end? whether the so-called chemical elements may not be, after all, mere allotropic conditions of fewer universal essences? whether, to renew the speculations of the alchemists, the metals may be only so many mutations of each other, by the power of science mutually convertible? There was a time when this fundamental doctrine of the alchemists was opposed to known analogies; *it is now no longer opposed to them, but only some stages beyond their present development.*

As we possess in the nitric oxide gas, or bin-oxide of nitrogen, a test of the presence of oxygen gas—so we also have a test of the specific condition of oxygen gas characterised by the name of ozone. A mixture of iodide of potassium and starch solution constitutes this test, and it may be conveniently applied by imbuing bibulous paper with it, and allowing the paper to dry. Slips of this paper I here have already prepared, and let us see to what deductions we arrive:—I first dip a slip of the paper moistened into a bottle filled with oxygen gas as just prepared from the chlorate of potash and black oxide of manganese. The result is negative, you will observe, the colour of the paper undergoing no change. I now dip it into a bottle of gas which is also oxygen, but it has been subjected to the remarkable change of ozonisation, by a process which we shall presently go through. *This* slip of paper, observe, becomes tinged blue, demonstrating a very remarkable quality to be possessed by this gas—very different to those manifested by oxygen gas, as we have seen it hitherto. The ozonised gas, moreover, has a peculiar smell, whilst ordinary oxygen gas is totally devoid of all smell; moreover, it has other properties quite distinctive, as we shall presently see. Into a bottle containing it I now pour this blue solution—a solution of sulphate of indigo, and you will observe with what rapidity the solution becomes bleached: if I take a bottle of common unozonised oxygen, and pour into it a portion of indigo solution, no bleaching result supervenes, thus manifesting a remarkable difference also in this respect. Ozonised oxygen, moreover, exercises a remarkable influence over certain odours—thus, if a piece of tainted meat be immersed in this gas the effluvium is instantaneously destroyed; and if sheets of silver foil be plunged into it, the metal soon crumbles into dust—the oxide of silver. In point of fact, although ordinary oxygen gas exert no agency upon the metal silver, yet ozonised oxygen attacks it so readily and so violently, that silver, under the operation of the latter, can no longer be regarded in the light of a noble metal. The result of the operation of ozonised oxygen upon silver not only illustrates the peculiar agency of ozone,



but demonstrates its chemical identity with oxygen, the result of its action upon silver being no other than oxide of that metal. Another means of demonstrating the identity of the two consists in passing ozonised oxygen through a red-hot tube. This operation is so destructive of the ozonised state, that the gas goes in *ozonised oxygen* at one end of the tube, and comes out in the state of ordinary oxygen at the other.

But it is time to generate some of this ozonised oxygen, and show how it is prepared. It is produced, as I have already announced, during the action of an electric machine, but there are readier means of preparing it than this. The most ready is that which I shall now adopt. It consists in the slow action of phosphorus upon oxygen or atmospheric air. Having demonstrated that the bottle of atmospheric air before me contains no ozonised oxygen, by means of the paper slip dipped in a solution of iodide of potassium and starch, I now throw into the bottle a little water and a stick of phosphorus, and allow all to remain for the space of a few seconds, when, on again immersing the paper slip, it changes colour, assuming a tint of blue, as was the case just now when we were dealing with oxygen, previously known to be in the state of ozone. You may think, probably, that in this instance the resulting change is due to the floating vapours of phosphoric acid. It is not so: phosphoric acid is readily soluble in water, yet I may pass this ozonised gas through water again and again without in the least degree destroying



or modifying its distinctive qualities. Of the numerous remaining methods by which ozonised oxygen or ozone may be prepared, the limits of the time to which I am restricted only permit of my demonstrating one. Taking ing this glass jar, I first demonstrate by the usual test of iodide of potassium and starch paper the total absence of ozone. I now pour a little ether into the jar, and still there exists no ozone; but immediately that I heat a glass rod in a spirit-lamp flame, and immerse it heated, but not too hot, observe, that on testing the contents of the jar, there is abundant evidence of ozone. By means of these slips of prepared paper, ozone may be recognised wherever it may exist, and its presence will be discovered naturally formed in many localities. Thus it may be generally recognised in air which has swept over the ocean, although generally absent in air which has passed over large tracts of land. It will be readily inferred, from what we know of ozone, that it must necessarily be formed very extensively in nature's grand economy, and it is doubtless intended to subserve some highly important ends. Schönbein has speculated on its relations to health, and disease; speculations upon the consideration of which I am precluded entering on this occasion.

The most casual reflection on the qualities of ozone will be sufficient to cause an appreciation of its influence on the change of eremacausis, or decay. I have before me a piece of wood which has been subject of this decaying influence. It retains its external shape, but is brittle, devoid of tenacity, pulverulent. The change which this wood has undergone seems to present many analogies to the effect of slow combustion; and this, indeed, may be accepted as the fact. Doubtless, this ozonised condition of oxygen has been a main agent in effecting the result.

Nor is the half quiescent, half active condition of oxygen peculiar to the element in the state of gas, for, in certain solids, we find a condition very analogous to it. With the peculiar substance gun-cotton, you are doubtless familiar; its discoverer was M. Schönbein also, who has been particularly fortunate in unravelling the mysterious agencies of oxygen. Other forms of lignine or woody tissue may be made to assume the peculiar condition of gun-cotton by similar treatment. Thus we may have gun-sawdust, and what may be termed gun-paper, of which I have a specimen before me. More properly speaking, this is a specimen of what was gun-paper once. It is now no longer so, for, observe, it burns like common paper, and on applying to it a slight amount of force it breaks. It has no longer the usual tenacity of paper; it is decayed—having assumed a condition very similar to that possessed by decayed wood. Now, it appears to me that we here may recognise, by comparing the present condition of this gun-paper with its primitive state, an analogy with that presented by ozone. In the original wood the oxygen existed in what may be designated its normal condition, or state of inactivity; then followed the intermediate, semi-active condition of oxygen, as it existed in the paper when the latter became endowed with explosive properties;—and what followed next? Why, this: a process of slow combustion, so to speak, ensued. Instead of being consumed at once with explosion, as it would have been had flame been applied, the ligneous matter became preyed upon slowly by a species of lingering combustion; and you see the result. The paper has become subjected to the effects of eremacausis, or dry decay. Slowly, but surely, oxygen has been exerting its powers. That force which would have been explosive, had it become concentrated into one effort, has expended itself in a long continued, progressive change. And here let us reflect awhile on the fallacious interpretations we give to the phenomena of nature. The majestic phenomena of combustion bespeak our observation and rivet our attention, because of their imposing grandeur; yet these are but spasmodic efforts in the grand economy of the material world,—occurrences of now and then. The slower, but continuous progress of the elements to their appointed resting-place,—the silent, tranquil, ever progressing, metamorphic changes involved in the phenomena of decomposition and decay, these we count for nothing and pass unheeded by. Yet with all their majesty—with all their brilliancy—all their development of tremendous energy, what are the phenomena of combustion in the grand scheme of the universe compared with these? When the loud crash of thunder, or the lightning's flash, awakens us from our thoughtless abstractions or our reveries, our feelings become impressed with the grandeur of Omnipotence, and the might of the elements he wields; yet the whole fury of thunderstorms—what is this in comparison with those electric energies which silently and continuously exert themselves in every chemical change! Why, the electric force residing in a single drop of water, and disturbed when that water is decomposed, is, of itself, greater than the electricity of a whole thunderstorm. Those of us who merely look to the brilliant phenomena of nature appreciate but little the grandeur of her forces! Those of us who limit our appreciation of the powers of oxygen to the energies displayed by this element in its fully active state, form but a very inadequate idea of the aggregate results accomplished by it in the economy of the world! Let us for an instant contemplate the enormous amount of oxygen employed in the function alone of respiration, which may be considered in the light of a slow combustion. For the respiration of human beings, it has been calculated that no less than one thousand millions of pounds of oxygen are daily required, and double that quantity for the respiration of animals, whilst the processes of combustion and fermentation have been calculated to require one thousand millions of pounds more. But, at least, double the whole preceding quantity,—that is to say, twice four thousand millions of pounds of oxygen have been calculated to be necessary altogether—including the amount necessary in the accomplishment of the never ceasing functions of decay.

As stated in pounds, we can hardly create to ourselves any definite idea of this enormous amount; the aggregate is too vast, too overpowering. It is scarcely to be grasped by our senses when reduced to tons, of which it corresponds with no less than 7,142,847 per day.

AMOUNT OF OXYGEN REQUIRED DAILY,

Whole population . . .	1,000,000,000
Animals	2,000,000,000
Combustion and fermentation	1,000,000,000
	4,000,000,000
	2
Oxygen required daily .	= 8,000,000,000 lbs.

Tons.
7,142,857 in a day.
2,609,285,714 in a year.
260,928,571,400 in a century.
15,655,714,284,000 in 6,000 years.
Whole quantity, 1,178,158,000,000,000.

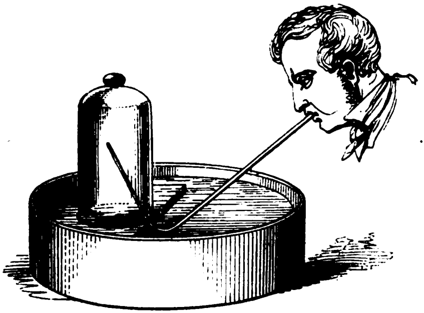
Such being the daily requisition of oxygen in the economy of nature, how great must be the total quantity existing in the world! Why, between one-half and two-thirds of the crust of this globe and its inhabitants are composed of oxygen. This will be manifested to you most conveniently by inspecting a diagram wherein the demonstration is made clear.

AMOUNT OF OXYGEN IN THE WORLD.

Animal	Principles	1/4	3/4	Oxygen is 1/2 or 2/3 of the globe.
	Phos. lime	3/7		
	Water	8/9		
Vegetable	Principles	1/3	4/5	
	Water	8/9		
Mineral	Silica	1/2	1/2	
	Alumina	1/3		
	Lime	2/3		
Ocean and waters		8/9		
Atmosphere		1/5		

Time presses, or I would expatiate on several of the functions in which oxygen plays so important a part. I would have entered more extensively into the beautiful function of respiration, and have shown the beneficent economy by which the oxygen of the air inspired is made to remove that very substance from the animal economy which vegetables require: I would have traced the analogies between combustion and respiration, but for all this there is not time: probably, too, these considerations may be postponed with some advantage, until we come to speak of the element, carbon. A few simple experiments, however, illustrative of the nature of respiration, I must not omit.

The first has for its object to demonstrate, that air which has been taken into the lungs and expired, will no longer support combustion. A similar effect then appears to have been produced upon it to that incident on the burning of a combustible. We can go further, and demonstrate the nature of the substance which air respired has been the agent of consuming. We can prove it to have been carbon, by agitating air thus respired with lime water, when the peculiar milkiness so characteristic of carbonic acid, will be made apparent.



And now, having cursorarily glanced over the leading points of oxygen—having drawn your attention to its enormous distribution in nature; to its existence in the quiescent state; to its condition of intense activity; and, lastly, to the peculiar ozonic modification of it—I will conclude this imperfect sketch with some remarks on the strange condition of allotropism, of which the condition of ozone is only one out of several manifestations. There was a time, and that not long ago, when it was held amongst the fundamental doctrines of chemistry that the same body always manifested the same chemical qualities, excepting only such variations as might be due to the three conditions of solid, liquid, and gas. This was held to be a canon of chemical philosophy as distinguished from alchemy; and a belief in the possibility of transmutation was held to be impossible, because at variance with this fundamental tenet. But we are now conversant with many examples of the contrary; and, strange to say, no less than four of the non-metallic elements, namely oxygen, sulphur, phosphorus, and carbon, are subject to this modification. The train of speculation which this contemplation awakens within us, is extraordinary. If the condition of allotropism were alone confined to compound bodies,—that is to say, bodies made up of two or more elements, we might easily frame a plausible hypothesis to account for it; we might assume that some variation had taken place in the arrangement of their particles. But when a simple body such as oxygen is concerned, this kind of hypothesis is no longer open to us,—we have only one kind of particle to deal with, and the theory of altered position is no longer applicable. In short, it does not seem possible to imagine a rational hypothesis to explain the condition of allotropism as regards simple bodies. We can only accept it as a fact not to be doubted, and add the discovery to that long list of truths which start up in the field of every science, in opposition to our most cherished theories and long received convictions.

INTRODUCTION TO LECTURE II.

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CHLORINE—ITS SYNONYMES, ETYMOLOGY, AND HISTORY NATURAL HISTORY, PREPARATION, AND QUALITIES.

SYNONYMES, &c.—Chlorine, from χλωρὸς, green. (Davy.)

Dephlogisticated muriatic acid. (Scheele.)

Oxymuriatic acid. (Lavoisier.)

HISTORY.—Discovered by Scheele in 1774, and called by him *dephlogisticated muriatic* or *dephlogisticated marine acid.* If we regard the term phlogiston as synonymous with hydrogen, then Scheele's appellation is quite accordant with our present notions of the chemical constitution of chlorine. Lavoisier and his colleagues, when arranging their chemical nomenclature of chemical bodies, termed it oxymuriatic, or oxygenised muriatic acid, under the impression that it was a compound of hydrochloric acid plus oxygen. In giving to chlorine this name, there can be no doubt that Lavoisier and his colleagues were influenced by a preconceived notion of oxygen being the universal principle of acidity. It remained for Sir H. Davy, in 1810, to demonstrate that the gas in question could not be proved to contain oxygen, nor had it been resolved into simpler elements; hence, according to the logic of chemistry, it must be regarded as a simple body. He applied to it the expressive appellation chlorine, on account of its yellowish-green tint.

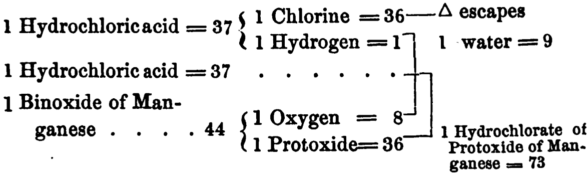
DISTRIBUTION AND NATURAL HISTORY.—Chlorine, although never existing naturally in an uncombined state, is, when united to other elements, a large constituent both of the inorganic and organic kingdoms. In the former it exists combined with sodium, constituting enormous beds of table salt. In the ocean it not only exists combined with sodium, but also with calcium, magnesium, and potassium. In the organic kingdom it is found as a constituent of both animals and vegetables; existing in the greater number of animal liquids, and in various fluids and secretions of plants.

PRODUCTION OF CHLORINE. — *Process I.* — By mixing together, and heating in a retort, one part, by weight, of coarsely powdered binoxide of manganese, and two parts, by weight, of hydrochloric acid.

Theory of the process.—Peroxide or binoxide of manganese is composed of two equivalents oxygen plus one equivalent of manganese. Protoxide of manganese, of one equivalent of manganese and of oxygen respectively.

Hydrochloric acid will not combine with binoxide of manganese, although it readily combines with protoxide.* The decomposition therefore resulting from the mixture of binoxide of manganese and hydrochloric acid on the application of heat, is as follows. The hydrogen of one portion of hydrochloric acid, uniting with one equivalent of oxygen of the protoxide, forms water; whilst another portion of hydrochloric acid uniting with the resulting protoxide of manganese, forms hydrochlorate of the protoxide of manganese; and chlorine escapes.

This decomposition furnishes an instance of what is occasionally termed predisposing affinity. That is to say, in the present case, one equivalent of oxygen is liberated from the binoxide of manganese in order that the latter may become protoxide, for the purpose of uniting with hydrochloric acid. The decomposition may be thus represented by a diagram:—


1 Hydrochloric acid = 37
1 Chlorine = 36
Δ escapes
1 Hydrogen = 1
1 water = 9
1 Hydrochloric acid = 37
1 Binoxide of Manganese 44
1 Oxygen = 8
1 Protoxide = 36
1 Hydrochlorate of Protoxide of Manganese = 73

Process II.—By putting into a glass retort, and distilling, a mixture of four parts by weight of common salt, one part of binoxide of manganese, two of sulphuric acid, and two of water.

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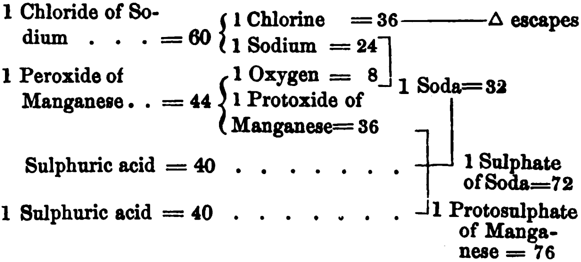
* This is the *simplest* explanation of what takes place—but whether a hydrochlorate of protoxide of manganese, or a chloride of manganese be formed, is doubtful.

Theory of the process.—The rationale of the evolution of chlorine, when sulphuric acid, peroxide of manganese, and common salt are distilled, is intimately connected with and dependent upon the fact that protoxide, not binoxide of manganese will combine with sulphuric acid. Hence protosulphate of manganese is formed, and oxygen gas would be liberated if chloride of sodium were absent. This salt, however, being present, the nascent oxygen unites with sodium to constitute soda; which immediately unites with sulphuric acid to form sulphate of soda; whilst chlorine being left uncombined, escapes in the gaseous condition. The decomposition may be simply expressed by a diagram.


1 Chloride of Sodium . . . = 60
1 Chlorine = 36
Δ escapes
1 Sodium = 24
1 Peroxide of Manganese . . = 44
1 Oxygen = 8
1 Soda = 32
1 Protoxide of Manganese = 36
Sulphuric acid = 40 . . . .
1 Sulphate of Soda = 72
1 Sulphuric acid = 40 . . . .
1 Protosulphate of Manganese = 76

PROPERTIES.—Weight of 100 cubic inches at a barometric pressure of 30 inches, and temperature of 60° F. = 76·59 grains.

Specific gravity, 2·470.

Atomic or equivalent weight, = 36 (nearly).

Atomic or combining volume, hydrogen being $\boxed{\text{H}} = \boxed{\text{Cl.}}$

At common temperatures and pressures chlorine is a gaseous fluid, which physical condition it maintains, if perfectly dry, at temperatures much below 0. Chlorine, however, forms with aqueous vapour, at a temperature of 32° F., a crystalline compound of chlorine and water (*hydrate of chlorine**).

Under cold and pressure gaseous chlorine may be converted into an amber coloured fluid, and it was one of the first gases thus reduced to fluidity by Mr. Faraday.† The compressing force was that of the gas's own elasticity, and was thus applied. Some of the hydrate of chlorine, just treated of, was put into a small bent tube, hermetically sealed, and a gentle heat applied. The hydrate of chlorine was by this treatment decomposed, and chlorine was liberated, which condensed into a fluid at the cold extremity of the tube; where two distinct liquids were found. The uppermost and lightest of these was merely a solution of chlorine, but the underlaying stratum was amber coloured, separable from the other by careful distillation, and did not solidify at 0. This means of effecting the condensation of gaseous bodies, namely, by the force of their own elasticity, has been successfully applied to many others besides chlorine.

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* See Quarterly Journal xv.

† See Phil. Trans., 1823, p. 160.

At a temperature of 60° F. water absorbs two volumes of chlorine. The solution has a specific gravity of 1·008, is of a pale yellow colour, has an astringent nauseous taste, and, if aqueous moisture be present, a bleaching agency. Chlorine is not a combustible, but a supporter of combustion; the results of such combustion presenting a general analogy to the results of combination with oxygen: viz., some are acid, as hydrochloric, hydrobromic, hydriodic acids,—whilst others are not acid, and are simply termed chlorides; as chloride of magnesium, of sodium, of calcium, &c. The presence of free chlorine may be recognised by its colour, odour, and bleaching quality; by its capability of dissolving leaf gold; and by its action on soluble salts of silver, with which it occasions a white curdy precipitate, insoluble in nitric acid, but soluble in ammonia.

BROMINE—ETYMOLOGY, HISTORY, NATURAL HISTORY, PREPARATION AND PROPERTIES.

ETYMOLOGY.—Bromine, from βρωμος, *graveolentia*, on account of its peculiar smell.

HISTORY.—Bromine was discovered by M. Balard, of Montpelier, and first described in the *Annales de Chim. et Physique*, for August 1826. It was originally obtained from the uncrystallisable residue of sea water after evaporation, but the chief sources of it at this time, are the saline springs of Theodorshall, near Kreutznach, Germany.

NATURAL HISTORY. — Bromine is extensively, though sparingly, diffused throughout the whole ocean and certain mineral springs; always in the state of combination.

PREPARATION. — The method of preparation, or extracting bromine from its combinations, whether in the ocean or in mineral springs, is as follows:—Having evaporated the bromine-containing liquid, and having thus effected the separation of readily crystallisable bodies, chlorine is transmitted through the bittern, or fluid which remains. Chlorine having the power to effect the decomposition of bromides, bromine is set free, and remains dispersed through the fluid. Ether is now added, in which fluid bromine is soluble, hence an ethereal solution of bromine floats on the surface. All that now remains consists in effecting the separation of bromine and ether. Distillation cannot be had recourse to, since both chlorine and bromine are exceedingly volatile; therefore a somewhat complex mode of procedure is rendered necessary. The ethereal solution being saturated with potash, two bromine salts are formed; namely, bromide of potassium, and bromate of potash. These two salts being collected and exposed to a red heat, bromide of potassium alone remains. This salt being mixed with binoxide of manganese and sulphuric acid, yields bromine by distillation.

Properties.—Bromine, at ordinary temperatures, and pressures, is a deep brown liquid, of very peculiar odour. Its specific gravity is about 3. It may be solidified by exposure to a temperature somewhat below 0. It does not conduct electricity. Is sparingly soluble in water, with which it forms a hydrate at low temperatures, like chlorine. In alcohol bromine is more soluble,—but chiefly so in ether. It is a bleaching agent,—and a supporter of combustion, but not a combustible.

IODINE.—ETYMOLOGY, HISTORY, NATURAL HISTORY, PREPARATION, AND PROPERTIES.

Etymology.—*ἰώδης, violaceus.*

History.—Iodine was discovered in 1812, by M. Courtois, a chemical manufacturer at Paris*, but for a knowledge of its chief chemical relations we are indebted to Sir H. Davy.

Natural History.—Iodine, like bromine, is widely, though sparingly distributed. In the inorganic kingdom, it is a constituent of all sea water, and many springs, also in certain mineral species;—thus, in certain Mexican silver ores, according to Vauquelin;† and Bustamenta detected it in a white-lead ore from Mexico;‡

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* Vauquelin, Ann. de Chim. xc.; Gay Lussac, *ibid*, lxxxviii. xc. and xci.; Davy, Phil. Trans. 1814.

† Ann. C. et P. xxix.

‡ Ann. Ch. et de Ph lxxii.

—of numerous fuci, certain sea mollusks, and other animals still higher in the scale of creation. Iodine is now chiefly obtained from kelp, or the fused ash of certain sea-weeds more especially the *fucus palmatus* and *vesiculosus.*

PREPARATION.—Iodine is prepared from kelp in the following manner:—An aqueous solution of kelp, is evaporated, until all readily crystallisable bodies separate. The mother water is then evaporated to dryness, the residue mixed with black oxide of manganese and sulphuric acid, and distilled.

Theory of the Process.—The residue of the evaporation of kelp solution being a mixture of iodide of sodium with iodide of potassium and magnesium, these salts, especially the former, may be regarded as the proximate source of the resulting iodine; and by transposing chloride of sodium for iodide of sodium, &c., the general chart of decomposition given in the diagram relating to the evolution of chlorine, it will apply in this case.

PROPERTIES.—A dark resplendent looking crystalline solid at ordinary temperatures and pressures; crystallises in the rhombohedral system of Weiss and Mohs;* colour, bluish black. When heated, iodine evolves violet coloured fumes, whence the term iodine, from *ιώδης violaceus*, is derived. Fuses at 228° F., and at 350° F. boils. 100 cubic inches of its vapour weigh 270 grains. Hence its specific gravity, air being unity, is 8·7, and it is 126 times heavier than hydrogen, which also is the ratio existing between their atomic weights. Like chlorine and oxygen, it is evolved at the positive electrode or anode, of a voltaic combination,—and hence it is an anion. Like chlorine and bromine also, it is sparingly soluble in water—namely, about one part in 7000. In alcohol and ether, it is far more soluble. When added to a solution of potash or soda, two salts are formed in either case, iodide of potassium and of sodium respectively. The distinctive test for iodine is solution of starch, with which it strikes a deep blue colour. The solution, however, must be cold, and no alkali must be present.

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* The primitive form of its crystal being a rhombic octohedron. (Buchner's Repert für die Pharmacie, 2te Reiter, Band xx. S. 43.)

LECTURE II.

CHLORINE. BROMINE. IODINE.

MATERIALS AND APPARATUS REQUIRED FOR ILLUSTRATING THE LECTURE.

Mixture of hydrochloric acid and peroxide of manganese in a retort, for the purpose of generating chlorine.

Pneumatic water-trough, jars, and bottles, for the purpose of collecting chlorine.

Some chlorine collected.

An aqueous solution of chlorine.

Table of the weight of chlorine.

Phosphorus.

Sulphur.

Oil of turpentine.

Deflagrating ladles.

Glass plates.

Piece of charcoal on copper wire.

Blow-pipe and spirit-lamp, for the purpose of making the charcoal red-hot.

Powdered antimony.

Copper leaf loosely thrust into a glass jar, to match with another glass jar containing chlorine.

A piece of blue litmus paper and another piece of paper stained red with peach-wood, suspended in a stoppered jar.

Solutions of sulphate of indigo in water.

Bleached and unbleached flax, and a piece of brown holland.

Specimens of rock salt.

Specimen of sodium, copper ladle, spirit-lamp, and copper wire.

Jar with saturated solution of salt.

Balls of ebony and beech.

Some eggs.

Screen of rock salt.

Screen of glass, hot ball, and phosphorus.

Iodine.

Bromine.

Starch solution.

A glass globe for displaying, when hot, the violet-coloured vapour of iodine.

The non-metallic simple bodies which I design to be the subjects of discourse on this occasion are Chlorine, Bromine, and Iodine, bodies which constitute a well-marked triad, as possessing analogous properties amongst themselves, and which, although they are not so largely distributed as oxygen, play nevertheless a very important part in the world's economy.

First, then, directing our attention to Chlorine, let us observe the more obvious physical properties of the element, of which we have specimens before us already prepared. Like oxygen, this element, when liberated from combination and obtained in its free or uncombined state, is a gas; but the physical qualities of chlorine differ from those of oxygen in several respects. In the first place, you will observe it to be endowed with a peculiar yellowish-green colour, whence its name is derived. In the second place, it possesses a highly irritating, remarkable odour, only too evident despite all our precautions, and which is altogether distinctive. Although gaseous, then, it appears that chlorine differs from oxygen in its most obvious physical properties. Again, it may be demonstrated by an experiment which could not be conveniently performed here, that it possesses a marked difference as to weight. 100 cubic inches of oxygen gas weigh, as we have seen, 34·6 grains; whereas 100 cubic inches of this gas weigh 76·59 grains; hence it is more than twice the specific gravity of atmospheric air; but these relations of weight are most conveniently manifested by a diagram.

ABSOLUTE AND RELATIVE WEIGHT OF CHLORINE GAS.

	Grains.
100 cubic inches weigh	76·59
Compared with air is	2·47
Compared with hydrogen . . .	36·

Such are amongst the most obvious of the physical properties of chlorine: the others had better be discussed after we shall have liberated some of the gas from one of its compounds. The great magazine of chlorine in nature is rock salt, composed, as we shall presently demonstrate, of this element in combination with the metal sodium. From this substance it may be readily, with proper management, developed, and from which we will proceed to develop it now. For this purpose a mixture of rock salt and black oxide of manganese, in suitable proportions, is put into a glass flask, or retort, and a mixture of oil of vitriol and water being added, heat is applied. The chlorine passes over and may be collected by the aid of the pneumatic trough.

[It will not be out of place here to admonish those who, not being possessed of a laboratory, desire to learn by experiment the properties of chlorine—to operate in a room altogether free from valuable furniture, but more especially from coloured hangings. Chlorine is not only a bleaching agent, but it is also destructive to organic compounds: hence the injurious results of its escape would become painfully manifest.

With regard to the preparation of chlorine, it may be made either from—

(1.) A mixture of common salt and peroxide of manganese, with enough sulphuric acid to form it into a paste.

(2.) A mixture of peroxide of manganese, and enough hydrochloric acid (syn. muriatic acid—spirit of salt) to form it into a paste. The dry materials, in either case, are to be put into a glass retort, and the respective acid (sulphuric or hydrochloric acid) added. A moderate heat (that of a spirit-lamp) now being applied, chlorine comes over, and may be collected.

Having put the dry materials for generating chlorine into the retort, and added the desired amount of acid, the operator should not immediately apply the source of heat, but, holding the retort above the level of the eye, he should observe whether the glass has become thoroughly wetted by the acid, or whether a dry spot still remains. If the former, heat may be applied; if the latter, all heat should be withheld until the mass, by agitation, has become thoroughly incorporated, and the dry spot disappears. Had heat been applied at once, without this precaution, a fracture of the retort would most probably have ensued, and the contents being spilled, the whole atmosphere would have become pervaded with chlorine vapours.

With regard to the mode of collecting chlorine, some authorities recommend its collection over *hot* water, inasmuch as cold water absorbs a considerable amount (about twice its own volume). This plan, however, is attended with the serious disadvantages of causing the chlorine to enter the bottle hot, and for that reason rarefied: hence, when it cools and contracts the stoppers of the bottles are found not unfrequently to be permanently fixed. Cold water should be employed. Except it be agitated whilst the gas is passing through, so little of the chlorine is absorbed that the amount of loss is too small to be of consequence.

Inasmuch as chlorine is a very irritating gas, every care should be taken to prevent its escape into the atmosphere. Hence, in the operation of collecting it, those first portions which pass over, and which are necessarily largely contaminated with the atmospheric air originally contained in the retort, should not be allowed to escape, but should be collected in a large jar placed ready for the occasion; and, being collected, the mouth of the jar (inverted) should be shifted, under water, into a plate, and the jar and plate removed into the open air, where the impure gas should be *thrown away.* That is to say, the plate being removed, and the jar being turned mouth uppermost, the water contained in the plate should be thrown into it, well agitated, and poured out. During the whole of this operation of throwing away the nostrils should remain closed.

Every care should be taken in bottling up chlorine for preservation to exclude water as much as possible, inasmuch as, under the agency of light, water and chlorine react, forming hydrochloric acid, which is so violently absorbed by water, that the stoppers of the chlorine bottles become often irremediably fixed, owing to external atmospheric pressure.

It is evident that, in collecting chlorine over a water-bath, some water must necessarily be included; but if, after stoppering up the bottle and inverting it, any quantity of water be observed, that would flow out if the stopper were partially withdrawn—it is better to do so at once. Of course, atmospheric air enters in the same proportion as water flows out, but, for all purposes of lecture demonstration, its presence is of no consequence; and if absolutely pure chlorine be required the water-trough should not be used.

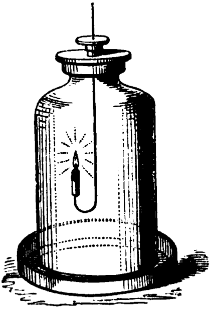
It has been remarked that, under the influence of light, chlorine gas and water mutually react; and hydrochloric acid results. Hence, if it be desired to bottle up chlorine for any considerable time, it is better that the bottles should be of black or deep-blue glass, and these bottles should be kept in a dark place. Both stoppers and mouths of the bottles designed for chlorine should be well lubricated with pomatum.]

MIXTURE FOR LIBERATING CHLORINE.

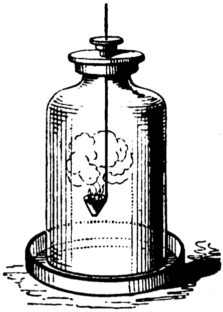
	Parts.
Common salt	4
Oxide of manganese	1
Sulphuric acid	2
Water	2

Although chlorine may thus be readily collected over water, as we collected oxygen, yet it is soluble, especially under agitation, in this liquid—a quality upon which many of the most useful economical applications of chlorine depend. A volume of water at the temperature of 60° dissolves its own bulk of this gas, and the solution may be readily effected by throwing a little water into a bottle holding chlorine and agitating the contents. In conducting this experiment, I take care to remove the ground-glass stopper, and supply its function with a flat glass plate, or valve;—the rationale of which precaution is as follows:—The absorption of chlorine generates a partial vacuum in the bottle, when the external atmosphere exerting its pressure upon the stopper renders its removal difficult, or perhaps impossible. A glass valve, however, may be slid laterally off the bottle's mouth, notwithstanding the great external pressure to which it is subject.

We have now collected some vessels of gaseous chlorine, and we have also generated some solution of chlorine and water, let us therefore proceed to investigate some of the chemical properties of this element, and, in the first place, its powers as regards combustion.



We commenced our investigation of the properties of oxygen gas in relation to combustion by plunging into a vessel containing it a lighted taper. We will therefore repeat the experiment with chlorine. Having thoroughly ignited the taper, I immerse it, and now observe the result. How different is the play of affinities from those of oxygen under similar circumstances! The taper continues to burn, it is true; but how strangely, how different from its combustion in atmospheric air, or oxygen! The flame would seem to struggle for existence; feeble light is evolved, and dense fumes of carbonaceous matter pervade the vessel.



What, then, shall we infer from this phenomenon? Shall we at once decide, as does not seem irrational, that chlorine is not so good a supporter of combustion as oxygen?

Let us try another experiment. Instead of the taper, I now immerse in another jar of chlorine, a piece of phosphorus already burning. Mark the result! Combustion still proceeds, but in a very modified form. In oxygen gas the combustion of phosphorus is exceedingly brilliant, but here the light evolved is almost imperceptible. Not only is the combustive operation less brilliant than it would have been in oxygen, but less brilliant than in atmospheric air. Shall we hesitate now to decide that chlorine is a less powerful supporter of combustion than oxygen? Let us not decide upon this point even yet. Taking another piece of phosphorus, I dry it with blotting paper, put it into a copper deflagrating ladle, and plunge it without ignition into a bottle of chlorine gas. Mark the result now! Although the brilliant indications of powerful combustive energy, as made known by the evolution of great light and heat, are wanting, yet we notice a very extraordinary phenomenon, characteristic of some intense force in operation. We notice the phosphorus to take fire of itself, which is not capable of resulting in oxygen gas; although, when once ignited, combustion in that medium is very powerful. To have characterised this element, then, as being deficient in that energy necessary to support combustion would have been altogether fallacious and deceptive.

Nor is this spontaneous power of combustion restricted to phosphorus. If a slip of paper moistened in oil of turpentine be dipped into chlorine, a similar effect takes place,—the combustion in this instance being attended with the same development of carbonaceous fumes we observed when an ignited taper was immersed. Clearly then, this gas is endowed with an immediate power of activity which is very extraordinary—capable of manifesting itself in an intense, if not brilliant combustive energy.

Our demonstration of this quality of chlorine does not rest here: not only do certain combustible bodies—in the ordinary sense of the term—burn readily in it, but others considered, in the ordinary way of viewing things, incombustible. Into another jar of chlorine I now project a little of the metal antimony reduced to powder, when it immediately takes fire; and into yet another jar I dip some thin copper leaves, when combustion again ensues.* We are led, therefore, by experiments to modify all our first notions as to the degree of combining potency, capable of being manifested by this gas. The apparent anomaly of the languishing combustion in it, of a lighted taper, and of the evolution of carbon,—a remark which equally applies to our experiment with oil of turpentine—is accordant with all that we know of the laws of combustion. No exceptional theory is required for the explanation of this phenomena—no contrariety is involved. One symmetry of relation pervades the whole:—but in order that we should understand it, certain general laws involved in the phenomena of combustion require to be discussed. I cannot introduce this discussion more rationally than by the performance of another experiment, the result of which will strikingly manifest the intense activity on the one hand, and the combining relations on the other, of chlorine. I have here before me a piece of charcoal enveloped in a sort of cage made of copper wire, the wire itself being attached to a metallic disc and cork, as is usual in conducting experiments of this character. The charcoal I now ignite by means of the blow-pipe flame, and suspend it in a jar of chlorine. Observe the remarkable result. Although charcoal is a very combustible substance in atmospheric air and oxygen, whilst copper is the reverse, yet an inverted order of result here appears. The flaming charcoal is extinguished no less completely than if it had been plunged into water,—whilst the copper wire burns. Here, then, we have exemplified in this result the reason why sooty fumes appeared in the experiment with a taper and with oil of turpentine. The rationale is this. Chlorine happens to be endowed with a powerful combining affinity for copper and for hydrogen, whilst its affinity for carbon is so extremely slight that it cannot be made to unite with that element under the course of treatment we have followed. Hence it results that when a combustible made up of carbon and hydrogen, such as a taper, or oil of turpentine, is burned in chlorine gas, the hydrogen alone burns, and the carbon is evolved. We have also the reason why the illuminating power of flame in chlorine gas is so extremely weak, for it happens that the results of combustion are either vaporous or gaseous,—results which,

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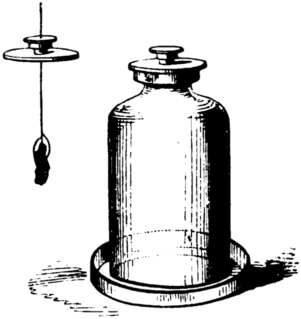
* The simplest plan of conducting this experiment consists in attaching to a hooked copper wire mounted on a cork and metallic disc—as was described in the lecture on oxygen—several sheets of copper leaf. The experiment may be more strikingly performed by filling loosely a globular glass vessel, mounted with a stopcock, with copper foil, thus producing a vacuum by means of the air-pump, screwing the stopcock to a jar of chlorine, opening a communication, and allowing the chlorine to rush in.



as I before explained in the lecture on oxygen, are unfavourable to the condition of luminosity.

Thus closes our examination of the element chlorine in relation to combustion; and now we may with interest ask ourselves, what would have been the consequence, so far as relates to combustion, had chlorine been the material of our atmosphere? Why, our most common notions as regards the combustibility of bodies would have to be inverted. Charcoal, so combustible now, would then have been totally incombustible; and those substances, forming so large a class, which are made up of carbon and hydrogen, would have only been susceptible of combustion in so far as concerns their hydrogen; the carbonaceous elements being evolved in dense fumes, as we have already seen. How far beyond the regions of mere chemistry do such phenomena as these lead us—how varied the contemplations to which they give rise! We see the whole physical economy of the universe so accurately poised, so beneficently, so admirably balanced, that not an alteration could be made without disturbing the economy of all! Then, again, consider the state in which chlorine naturally exists; and think of the greatness of the Omniscience which imposed that state upon it. Oxygen we have seen to constitute a large portion of our atmosphere—to be floating about untrammelled, uncombined. Had chlorine been thus permitted to waft about, how desolate would have been the world! Not an animal, not a plant could have lived. The function of life would have ceased! Even the mineral economy of the globe would have been reversed! Yet chlorine ministers to its own ends. Its compounds are amongst the most necessary to vitality; itself is useful in a thousand important applications. Ever beneficent in his regulations, the Creator has locked up this element in magazines of rock salt. There its destructive agencies are subdued; yet it can readily be called forth in its uncombined state by the ingenuity of man, and made subservient to his wants.

Passing from the investigation of chlorine as an agent in promoting the function of combustion, let us now proceed to the examination of some of its less violent manifestations. Of these the most remarkable, the most useful to man, is its property of bleaching or destroying colour. If I take a portion of indigo-solution, and agitate it with a little gaseous chlorine, the solution almost immediately becomes colourless; and repeating the investigation with other colours, a similar result ensues. If, instead of gaseous chlorine, I use an aqueous solution of the gas, the result is similar; the colour in either case being completely discharged. This property of chlorine is taken advantage of in many of the industrial arts. In the operation of bleaching linen and calico, chlorine, or a peculiar combination of it presently to be described, is now universally employed. It is also used in the more refined operation of calico-printing, for the purpose of producing white patterns on coloured ground. Permit me now to draw your attention to the property which chlorine has of being absorbed by water. Gaseous substances are difficult to apply—unmanageable; and a gas so injurious to the respiratory organs as chlorine is would have been extremely so. Its solution in water diminishes this inconvenience, and renders its employment comparatively easy.

A very elegant application of chlorine solution to bleaching purposes is made in the printing of bandanna handkerchiefs. The white spots which constitute their peculiarity are thus produced. First of all the whole fabric is dyed of one uniform tint, and dried. Afterwards many layers of these hankerchiefs are pressed together, between lead plates, perforated with holes conformable to the pattern which is desired to appear. Chlorine solution is now poured upon the upper plate, and, pressure being applied, is made to percolate the whole mass. The solution cannot however extend laterally further than the limits of the apertures, whence it follows that the bleaching agency is localised to the desired extent.

There exists, however, a more convenient absorbing agent than water in the substance lime, and it is to this circumstance that the most beautiful—the most refined applications of chlorine, as an agent in bleaching and in calico-printing, are due. I now take a bottle filled with chlorine, as is sufficiently evidenced by colour and by smell. Into this bottle I pour a small portion of slaked lime, close the bottle, and, agitating the contents, I await the result. Gradually the chlorine is being absorbed. The greenish yellow atmosphere has disappeared—the chlorine has been now disposed of so completely that no evidence of its existence remains. The lime has absorbed it all. The result is the substance commonly known by the name of chloride of lime, or, from its chief application, *bleaching* powder, and is prepared on a very large scale by bringing chlorine gas in contact with slaked lime, as I have just done. In this substance, although the chlorine has been absorbed, yet it is held with such little force that various decomposing energies readily cause it to be evolved. Thus, if I pour into a solution of this bleaching powder in water, a little sulphuric, or hydrochloric, or nitric acid, the gas is given rapidly off. Or if I expose some of the same powder to the ordinary influences of air and moisture, a continuous but very slow evolution of chlorine takes place. Thus, by combination with lime, the agent chlorine is rendered still more manageable than we found it in its aqueous combination,—occupying still less space, presenting fewer manipulative difficulties to be overcome. By availing ourselves of its capabilities, chlorine may be used with any amount of violence, so to speak, within the limits of its powers. We may cause it to be developed at once if we so desire, or we can effect its evolution by the slowest degrees. It is possible so to dilute this bleaching powder with water, that it shall exercise no bleaching effect of itself; but this effect shall be developed by the disturbing agency of a third substance. Thus, for instance, I have before me an exceedingly dilute solution of chloride of lime in water; so dilute, that a portion of blue indigo solution added to it is not perceptibly discoloured. But I now superadd a third or disturbing agency: I pour in a little acid; muriatic, sulphuric, nitric, or citric, and the result is decoloration. A very beautiful application of this property is as follows. Suppose it to be desired, in the operation of calico printing, to produce a white pattern on a coloured ground; the colour being one of those removeable by the agency of chlorine. The desired result would be readily produced—is produced—by the following course of manipulation. The whole texture having been dyed with the colour in question, the form of the desired white pattern is impressed upon it by means of a stamp; the impressed substance containing some acid—say the citric—which possesses the property of liberating chlorine from a solution of chloride of lime.

I recently had occasion, when lecturing, vicariously, for my colleague Mr. Brande, on the operation of calico printing, to show that white figures were produced on a field of Turkey red by taking advantage of this principle. The entire fabric being first dyed, the desired part is laid on with a mordant of gum and citric acid. The fabric is now dried again, and still retains its universal tint of red. No sooner, however, is it dipped into a bath of chloride of lime, than the citric acid sets up just that amount of local decomposition necessary to effect the liberation of chlorine, which immediately produces its bleaching agency; the non-mordanted portions of the fabric remaining unchanged.

Under these circumstances, it follows from what we have seen that, the whole fabric being immersed in a solution of chloride of lime of the necessary strength, only those portions of the texture which have received the acid imprint will be bleached. Thus, we see that although chlorine is not like oxygen, endowed with an intermediate waiting state, yet we may accomplish something like it by combination with lime in the form of bleaching powder. Very analogous to its operation upon coloured bodies, does chlorine act upon odours and miasms. Hence it becomes an important agent in purifying the air from the floating germs of disease. Perhaps, however, in the true logic of chemistry, it is not *the* chlorine itself which is either a decoloriser or deodoriser, but oxygen. Perfectly dry chlorine is said to be devoid of bleaching agency, although precise demonstration of this is not easy, and aqueous vapour is considered to be indispensable in developing the result. On the adoption of this theory, the play of affinities would be as follows:—Chlorine would combine with hydrogen of the water to generate hydrochloric acid, and oxygen would be evolved. Regarding the practical effect of chlorine as a bleaching or disinfecting agent only, this intermediate play of affinities need not be taken cognisance of. It neither affects our argument nor prejudices our conclusions.

To be in accordance with popular expression, I have denominated the compound resulting from the action of chlorine gas on lime, *chloride of lime;* indeed, this bleaching powder was at first considered to be the result of a direct union between chlorine and lime, but now that view of its composition is exploded; and had it really been the case we should have had a body of altogether anomalous constitution. Some variety of opinion as to its exact constitution still exists, but it is believed to be a mixture of hypochlorite of lime, chloride of calcium, and water, as represented by the appended diagram:—

COMPOSITION OF BLEACHING POWDER.

$$\left.\begin{array}{lll} \text{2 Lime} \;.\;. & Ca_2 & O_2 \\ \text{2 Chlorine} \;. & Cl_2 & \\ \text{2 Water} \;.\;. & O_2 & H_2 \end{array}\right\} = \left\{\begin{array}{llll} \text{1 Chloride of calcium} & Ca & Cl & \\ \text{1 Hypochlorite of lime} & Ca & Cl & O \\ \text{2 Water} \;.\;.\;.\;. & & O_2 & H_2 \end{array}\right.$$

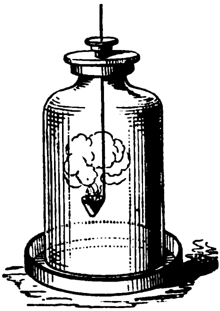
The discovery of this bleaching powder, and the manufacturing process for generating it on the large scale, are due to Mr. Mackintosh. The process consists in first slaking lime by pouring water upon it, when great heat is evolved, and the lime crumbles to powder. After the slaked lime becomes quite cold—for this is essential to the success of the process —it is placed in enormous chambers, and torrents of chlorine are forced in upon and through it — the process being continued until no more chlorine is absorbed. In point of fact the commercial operation of making bleaching powder, on the large scale, is precisely similar in principle to that which I have just performed.

We have hitherto regarded chlorine as existing uncombined. We have seen its great activity—we have learned how to modify its forces, and render them subservient to our ends. We have contemplated the wisdom of that provision by which this destructive element is confined in its prison-house of salt, whence it is liberated by degrees at the will of man. We have seen how it differs from oxygen, not only in primary physical qualities, but in being insusceptible of assuming an intermediate semi-active ozonised state. We have seen how the equivalent to this semi-active condition may be effected by proper means. Thus much, then, for chlorine as an uncombined agent. Now let us take a glance at its combinations.

At the head of all these—whether we have reference to the great quantity in which it exists throughout the globe, to its manifold uses, to its intimate connection with vital organism, or its chemical properties—is sea or rock salt; a binary compound of chlorine with the metal sodium. Our best introduction to a future consideration of this substance will consist in the performance of an experiment, the result of which is its artificial formation.

For this purpose I take a lump of the metal sodium. I place it in a copper deflagrating ladle.

set fire to it, and plunge it into a jar of chlorine, Combustion ensues,—but proceeds irregularly, and is retarded, now and then, on account of the formation of a coat on the surface of the sodium. This crust is common salt, generated by direct union of the chlorine with the sodium.



Chlorine, iodine, and bromine have been denominated *halogens*, from the circumstances of their forming combinations, of which sea-salt may be regarded as the type; and this would seem to be a fitting opportunity for reflecting upon the vicissitudes of theories, formed at one epoch of scientific development under the too confident assumption of their being in harmony with future discoveries.

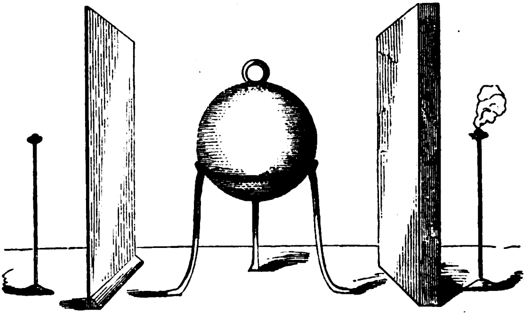
Thus, during the early part of the first French Revolution, Lavoisier reformed chemical nomenclature; substituting rational terms for the irrational ones hitherto applied to chemical substances. By Lavoisier a salt was defined to consist of the union of an acid with a base, and thus common salt was said to consist of muriatic (hydrochloric) acid in union with soda. Hence no sooner was common salt demonstrated to be a compound of chlorine with sodium, than it was no longer a salt, according to the Lavoisierian definition. A definition, however, should never do violence to a long-received and expressive common idea; therefore, with a view of avoiding this violence in the present case—with a view of obviating the startling proposition that common salt, the very type of all saline bodies, is no salt at all—chemists have introduced the term "*haloid salts,*" to indicate the chlorides, bromides, iodides, &c., combinations of chlorine, iodine, bromine, &c., with simple bodies. The haloid type of salts, thus interposed as an assumed exception to a general rule, is now regarded by some chemists as not the exception to, but the type of all other salts. Thus, for instance, applying the theory to the case of sulphate of potash, we may assume this salt to be made up of $S\ O_3\ K\ O$—that is to say, of sulphuric acid and potash; or of $S\ O_4\ K$—that is to say, of a hypothetical compound of one equivalent of sulphur, plus four of oxygen, and potassium. Substituting chlorine, iodine, or bromine for the hypothetical compound of $S\ O_4$, it is evident we should produce a haloid salt.

Looking at salt from a physical point of view, it is most wonderful to contemplate the amount of condensation in volume which takes place when chlorine and sodium unite. Even omitting all consideration of the chlorine, and having regard merely to the sodium, this condensation is enormous. Common salt contains more than its own bulk of sodium. No known amount of physical pressure could have so diminished the volume of the sodium. Then, when we come to consider the condensation the chlorine has assumed, the marvel is still greater.

TABLE SHOWING THE IMMENSE CONTRACTION OF BULK CAUSED BY THE UNION OF CHLORINE AND SODIUM TO FORM COMMON SALT.

	Weights.		S. Gravity.		Volumes.
Sodium	24	÷	0·93	=	25·8
Liquid Chlorine . .	36	÷	1·2	=	30.
Rock Salt	60	÷	2·5	=	24.

Thus, 24 parts by measure of common salt contain no less than 25·8 parts by measure of sodium (more than its own bulk), and no less than 30 parts by measure of liquid chlorine, 55·8 parts by bulk, compressed into 24. No known mechanical force could have accomplished this, yet it results from agency of chemical affinity! It is strange, again, that such an amount of condensation —of squeezing together of atoms—should be co-existent with such perfect transparency, for common salt is even more transparent than glass,—allowing a certain kind of radiant matter to pass, which stands on the confines of light and heat. I have here two transparent screens, one of salt—the other of glass. They both seem equally transparent, or, in other words, the radiant



matter of light seems to be transmitted with equal facility. Yet when we come to investigate the comparative transmitting power of the two screens for another kind of radiant matter—heat—we shall discover a manifest difference. If a heated metallic body—say a cannon ball—be taken and placed in the focus of a parabolic mirror, the radiant heat evolved will be reflected from another mirror towards its own focal point; in which if a piece of phosphorus be laid, combustion of the phosphorus will ensue. If now a glass screen be interposed, considerable impediment to the passage of radiant heat will result, and the phosphorus will not take fire as before. But the screen of rock salt, although much thicker than the one of glass, affects so inappreciably the passage of radiant heat that the phosphorus takes fire as before. This variation of power, possessed by different bodies, of transmitting heat has created the necessity of a new term that should stand in a similar relation to heat that the term transparency does to light. *Diathermaniety* is the term employed, and bodies possessing it are said to be diathermanous.*

Although the chief natural combination of chlorine is with sulphur, yet we occasionally find it associated with other metals, constituting natural ores; and in all these instances the tremendous energy of the element, which would have been so noxious, so destructive, is merged. Artificial combinations there are several—most of them characterised by qualities not dissimilar to those of chlorine itself. Of these artificial combinations, the one with hydrogen, constituting hydrochloric or muriatic acid, is the most important, but it cannot with propriety be brought under your notice until the characteristics of hydrogen shall have been discussed. With oxygen it unites in four known proportions, giving rise to four different substances, furnishing points of high interest and not a few peculiarities. Of these combinations let me now say a few words. Their proportional composition has been indicated in an accompanying diagram, and also their names. It remains, therefore, for me to point out the method of their preparation, and some of their leading qualities.

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* Whilst on the subject of rock salt, a very pretty experiment was performed, illustrative of the difference of buoyant power manifested by saline solutions of various densities. The experiment was as follows:—Into a tall glass jar was poured a quantity—some three or four inches deep—of brine—water fully impregnated with salt; and into this brine were put two ebony balls, two eggs, and two balls of beech wood. The ebony balls

COMBINATIONS OF CHLORINE WITH OXYGEN.

	Number of equivalents.		Parts by weight.	
	Chlorine.	Oxygen.		
Protoxide of Chlorine, Euchlorine, or Hypochlorous Acid . . .	2	2	72	16
Peroxide of Chlorine, Chlorous Acid, or Hypochloric Acid .	1	4	36	32
Chloric Acid	1	5	36	40
Perchloric Acid	1	7	36	56

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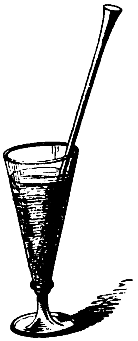
sank, and the beech wood balls and eggs swam. Water was now poured in, thus diminishing the specific gravity of the fluid; as a consequence of which the eggs were caused to be suspended midway in the liquid, whilst the ebony balls remained at the bottom, and the beech wood balls on the surface.

The first combination in the list was discovered by Sir H. Davy, and obtained by adding hydrochloric acid to chlorate of potash. This mode of production, however, although convenient, does not furnish us the compound pure; pure enough, nevertheless, to manifest its leading qualities.

Euchlorine is developed on the application to the mixed materials of a temperature not higher than 212° F., and is a gas—something like chlorine in appearance, although possessing a hue of deeper intensity, whence its name. Examined with reference to the intensity of combination subsisting between the two elements which form it, this gas is found to be held together by very weak affinity. Very slight causes suffice to decompose it into its two constituent elements, chlorine and oxygen; whence its most characteristic properties. A slight elevation of temperature above that of 212° accomplishes this result with explosion, as may be demonstrated by dipping into a small jar containing this gas a heated wire. Various organic bodies also decompose it, such as paper and flax, and cotton fibre. This great tendency which it possesses to liberate chlorine constitutes it a powerful bleaching agent, and, strictly speaking, it is the bleaching agent in the so-called chloride of lime. Like chlorine, it is capable of absorption by water, the resulting aqueous solution acquiring the colour, the taste, and the smell of the gas itself.

Our next oxygen-compound with chlorine mentioned in the list is also under common temperatures and pressures a gas—though, like chlorine and euchlorine, it may be condensed into the liquid state by proper manipulation. Its leading properties are, like the preceding, indicative of a loose combining power between its elements; being decomposed by the slightest causes, and liberating oxygen and chlorine with violent explosive energy. Hence, peroxide of chlorine is very dangerous to meddle with, and should only be prepared for experiment in small quantities. It is generated, like the preceding, from chlorate of potash; but instead of using hydrochloric acid as the liberating agent, we here employ the sulphuric.

The colour of this gas is still more brilliant than the colour of euchlorine, verging towards an orange-red. Its colour presents a similarity to the two preceding; still possessing a resemblance to the original chlorine, but having, nevertheless, a peculiarity of its own. A little phosphorus dipped into a tube containing this gas effects its immediate decomposition with violent explosion. This form of illustration is, however, dangerous. A more safe and at the same time more elegant way of demonstrating this reaction, consists in bringing phosphorus in contact with the gas under water at the very instant of its development. A conical wine-glass being chosen, a few small pieces of phosphorus are first thrown in, and the glass three parts filled with

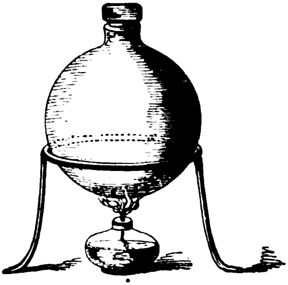


water. Crystals of chlorate of potash, about equal in quantity to the phosphorus employed, are now allowed to fall through the water and settle upon the phosphorus. All that now remains to be done is to bring sulphuric acid in contact with the two, which is easily accomplished by means of a small glass tube, or funnel, the extremity of either of which being brought in contact with the mixture, the sulphuric acid is caused to touch the solids without mixing with, and suffering dilution by, the water. Peroxide of chlorine is now rapidly evolved; phosphorus reacts upon it, combustion ensues, and the remarkable phenomenon is observed of flame under water.

Chloric acid, the third oxygen compound of chlorine mentioned in our list, presents some remarkable peculiarities. We have seen that in euchlorine, oxygen is held united with a very slight combining force, so that the two elements are balanced by feeble affinities and continually striving to get free; we have seen the characteristic qualities still predominant—its colour, its odour, its power of bleaching. Then, in peroxide of chlorine we have seen—as we might have anticipated *à priori*—all this restraint under forced affinities intensified. But, strange to say, in chloric acid we have a substance that, although it contains 40 parts by weight of oxygen united with 36 of chlorine—whereas euchlorine only contains 16 and peroxide of chlorine 32, united to the same quantity—is nevertheless endowed with distinctive qualities of its own. The qualities of chlorine are here all merged, veiled, masked, and those of the compound have reference not to chlorine but to oxygen. No amount of reasoning could have led us to this conclusion. It is the reverse of all that we might have supposed. Had reasoning alone without the demonstration of experiment been our guide, we should have reasoned thus: Inasmuch as thirty-six parts of chlorine only remain in a kind of forced combination with eight of oxygen, striving to become free and to exist in a separate state; inasmuch as the same remark applies with increased force to thirty-six parts of chlorine united with thirty-two of oxygen; therefore, the same amount of chlorine united with forty parts of oxygen should generate a compound of still greater instability. All our *à priori* reasoning would have tended to this conclusion. Yet how fallacious would it have been! Nay, more, the next and last oxygen compound of chlorine in the list is the most stable combination of all, notwithstanding that it contains no less than fifty-six parts by weight of oxygen, or seven equivalents united with thirty-six of chlorine!

Time admonishes me to pass from the element chlorine to the consideration of its two congeners, bromine and iodine; and as a preliminary to this, let me impress upon your memories a circumstance already mentioned. Chlorine, although existing as a gas when developed under ordinary circumstances, may nevertheless be condensed, by the application of sufficient pressure at a temperature sufficiently low, into a liquid. Do not associate, therefore, the idea of gaseous quality as a necessary condition to the existence of developed chlorine. The importance of bearing in mind this fact will be presently appreciated when we come to discuss the properties of bromine and iodine. Passing over all the circumstances which are foreign to the object I have in view, I shall at once bring a specimen of the element bromine before your notice. Under ordinary temperatures and pressures bromine exists as a fluid. This fluid, observe, is orange-red; thus presenting an intensified state of the colour of chlorine. Observe, too, that it is an exceedingly volatile fluid; that a drop of it poured into a warm bottle soon pervades the whole space as though with a permanently existing elastic fluid. If, then, the mean temperature of the atmosphere had been equal to the mean temperature of this bottle; or if, the temperature remaining as it is, atmospheric pressure had been sufficiently diminished, bromine would have presented itself to us like chlorine under the natural aspect of a gas. Observe, now, its smell. This resembles the odour of chlorine, but is much more pungent and disagreeable. So far, then, a complete series of analogies subsists between chlorine and this congener. Pursuing our investigations, we find that, like chlorine, bromine possesses bleaching agencies; like chlorine, its vapour sets fire to metals and phosphorus: in short, test it as we will, there is a complete cycle of analogies. Whilst these comparative facts are fresh in our minds, let us pass on to the investigation of iodine. Omitting, as before, all details concerning the history of this substance, observe it as it stands before us, a solid, crystalline, lustrous body, something in appearance like black lead.

The term iodine has been given to this element on account of the beautiful violet-coloured vapour it evolves when exposed to heat; and this is a phenomenon so significant of the presence of iodine in an uncombined form, that I must not omit to show it. Taking, therefore, a glass balloon, or flask, I heat it uniformly by means of a spirit-lamp; and now putting into it a few crystals of iodine, observe the beautiful violet-coloured vapour which results. The mean temperature to which I here heat the flask may be stated to be in round numbers about 100° F.: hence you will see that had this been the ordinary temperature of the atmosphere, iodine would have presented itself to us not naturally as a solid but as an elastic gas, like chlorine. This violet-coloured vapour is altogether characteristic of iodine, and when observed we require no further test of its presence. Frequently, however, this test is not eligible; hence another had to be devised. A very satisfactory and beautiful test of this kind we have in a starch solution, to which, if I add a little iodine solution, a deep blue tint results. This



development is also distinctive of iodine, and is eminently satisfactory when used with the necessary precautions; which are these. Neither the starch solution nor the iodine solution must be hot, nor must an alkali be present; under either of which circumstances the characteristic blue tint disappears.

The action of alkalis upon iodine affords one of the many indications of an analogy subsisting between the three congeners, chlorine, iodine, and bromine, and proves them to be true chemical congeners. The result is the formation of two salts, iodide of potassium and iodate of potash. If bromine be employed, *then* we have resulting bromide of potassium and bromate of potash; if chlorine, *then* chloride of potassium and chlorate of potash.

DECOMPOSITION WHICH ENSUES ON ADDING BROMINE TO POTASH.

1 Potash . . . . = 48 } 1 Bromate of Potash = 166
1 Bromine . . . . = 78 } 1 Bromic acid = 118
5 Potash = 240 { 5 Oxygen = 40 }
5 Potassium = 200 } 5 Bromide of Potassium = 590
5 Bromine . . . . = 390 }

Descending, therefore, in the scale of cohesive force we arrive now at a solid under ordinary atmospheric conditions. Yet it has been demonstrated that iodine is a true congener of chlorine and bromine. On regarding this vapour of iodine, moreover, a chromatic analogy will be immediately recognised between it and the two preceding simple bodies. The smell, too, presents an analogy, and so do the chemical relations of the three. Nor is this all: just as there is a progressive relation as to cohesion, so when we come to examine the combining powers of the three, as indicated by their respective equivalents or atomic weights, the same mutual relation will be rendered evident. This circumstance has been made the basis of some beautiful speculations by M. Dumas—speculations which have scarcely yet assumed the consistence of a theory, and which are only at the present time to be ranged amongst the poetic day-dreams of a philosopher:—to be regarded as some of the poetic illuminations of the mental horizon, which possibly may be the harbinger of a new law.

Regarding chlorine, bromine, and iodine as one triad, it will be seen, as we have observed, that between the first and the last there is recognisable a well-marked progression of qualities. Thus: chlorine is a gas under ordinary temperatures and pressures; bromine a fluid, iodine a solid: in this manner displaying a progression in the difference of cohesive force. Again: chlorine is yellow, bromine red, iodine black, or in vapour a reddish violet. Here we have a chromatic progression:—and, strange to say, if we refer to the atomic or equivalent weights of the three, a numeral progression will be observable. Thus, the atomic weight of chlorine is 35, of bromine 80, and of iodine

125*; and now, if the atomic weights of chlorine and iodine be added together and divided by two, the result will be the atomic number for bromine.

TABLE SHOWING THE NUMERICAL RELATION BETWEEN THE ATOMIC WEIGHTS OF CERTAIN TRIADS.

47	40	Potassium	
		Sodium	24
	7	Lithium	
89	20	Calcium	
		Strontium	44
	69	Barium	
80	16	Sulphur	
		Selenium	40
	64	Tellurium	

COMPARISON BETWEEN THE PROPERTIES OF CHLORINE, BROMINE, AND IODINE.

Chlorine . .	Gaseous . .	Yellow . .	36	162
Bromine . .	Fluid . . .	Red . . .	78	
Iodine . .	Solid . . .	Purple . .	126	

Thus, we have here one of the many scientific developments of late origin, which tend to lead us back into speculations analogous with those of the alchemists. Already have we seen that it is possible for one body to assume, without combination, two distinct phases of manifestation; therefore such of the so-called elements as are subject to allotropism, are not the unchanging entities they were once assumed to be; and now we find, after our attention has been led in the direction, that the triad of chlorine, bromine, and iodine not only offers a well-marked progression of certain chemical manifestations, but that the same progression is accordant with the numeral exponents of their combining weights. We seem here to have the dawning of a new light;—indicative of the mutual convertibility of certain groups of elements, although under conditions which as yet are hidden from our scrutiny.

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* The atomic weights of these and many other chemical substances slightly vary according to different experimenters. The numbers here given are adopted by M. Dumas.

With this remark I shall bring to a conclusion my sketch of the points or remarkable features of chlorine, iodine, and bromine. Their dangerous activity when uncombined, their quietude when held in combination, the similarity of their qualities and functions, their gradation in colour and cohesion, and, more than all, the curious law which the consideration of their atomic weights unfolds,—these appear to be the especial features of this interesting triad of non-metallic elements.

[It will be appropriate here to append an epitomised translation of an address made in French by M. Dumas, at the meeting of the British Association in the year 1851, on the relation existing between certain chemical triads. We extract it from the *Chemical Record* of July 12, 1851.

"The business of the Chemical Section was opened on Friday, July 4, by Dr. Faraday, who read a short communication on behalf of M. Bergemann, of Bonn, introducing to the notice of the association a new metal—or rather the hydrated oxide of a new metal, called Donarium.

"M. Bergemann had not sent the metal itself, fearing it would get oxidated during its passage here: he had preferred to send the hydrated oxide, which might easily be converted into the metal by any one who was desirous of so doing. Donarium, it appears, scintillates before the blowpipe, and in this respect bears an analogy to iron. If ignited it ceases to be soluble, except in sulphuric acid; and in this feature bears an analogy to cerium.

"During the discussion on the properties of this metal—which discussion was not long—Mr. Faraday said he was almost sorry to welcome any more metals; they fell on us like asteroids and confused our reckonings; his hopes were in the direction of proving that bodies called simple were really compounds, and might be formed artificially as soon as we were masters of the laws influencing their combination. These remarks were intended as an introduction of M. Dumas, who was announced to read a paper on certain relations between volume and simple weight—rendering it probable that certain bodies called atomic were really compounds.

"M. Dumas rose, and, after a graceful allusion to the freedom of English scientific men from scientific prejudices, said he would enunciate certain views over which he had speculated many years ago, whilst he was a labourer in the field of chemistry, and before he had been launched on the waves ot politics.

"M. Dumas had no paper; his discourse was unaided even by a note; but a narration so unhalting, a chain of reasoning more consequent, more lucid, more convincing, was not brought before the association. M. Dumas commenced with some very simple facts. He adverted to the different amount of solubility in water of lime, baryta, and magnesia. All were sparingly soluble in water, but the last, magnesia, the most sparingly of the three.

"Each substance was capable of uniting with sulphuric acid to form a sulphate. Of these three salts the sulphate of magnesia was the most soluble, yet magnesia itself was the most insoluble of the three bodies. Sulphate of lime was sparingly soluble in water, and sulphate of baryta quite insoluble. Why was this difference of solubility? Is there any reason to be offered? Must chemistry remain a crude assemblage of such undigested facts?

" A reason *could* be offered, and was seen in the fact that the solubility of a compound was in a direct ratio to the condensation of the substances entering into its formation.

"He had hitherto spoken of sulphates for the purpose of illustrating the law; but other examples quite as pertinent might be discovered. Thus there were two chlorides of mercury—one soluble in water, the other insoluble. Here again it was found that the insoluble compound was the product of major, and the soluble one the result of minor,—condensation. Chemical agency, M. Dumas went on to say, was the result of a force; which force was at once indicated and measured by combining or atomic numbers—which were in inverse ratio to their power of chemical agency. Thus the atomic or combining numbers of chlorine, bromine, and iodine, were respectively 35, 80, 125. Of this triad, chlorine would displace bromine; bromine would displace iodine. The three bodies, too, displayed other symmetrical gradations. Thus chlorine was most volatile, and iodine least; bromine being intermediate; and, as a consequence of the last deduction, chlorine was least dense, iodine most, and bromine intermediate.

"Thus we have a triad or series of three bodies displaying under three several aspects a symmetrical gradation. As chemistry becomes better developed it subjects itself to the scrutiny of mathematical investigation. Can mathematical investigation be applied to the triad of chlorine, bromine, and iodine? And, when applied, does it give a result accordant with incipient speculation? The atomic numbers of chlorine, bromine, and iodine, evidently supply us with the fairest data on which to exercise our calculations. These numbers cannot be feigned or strained: they have long been in existence—long before the ideas of M. Dumas were enunciated. Now, if there be any truth in the speculations of M. Dumas, the atomic or combining numbers of the three bodies in the triad being taken, half the sum of the extremes should be equal to the mean; or half 35, the atomic number for chlorine plus half 125, the atomic number for iodine should equal 80, the atomic number for bromine. And this indeed is the result, as will be evident on reference to the following simple arithmetical sum:—

Atomic weight of Chlorine	35
„ „ of Iodine	125
Sum .	160

2)160
Half that sum—— is the atomic weight of bromine!
80

"'Thus it follows,' to use the beautiful expression of M. Dumas, 'if we could by any means cause the union of half an atom of chlorine with half an atom of iodine, we might hope to get, to form, to create an atom of bromine!'

"We will not here stop to cavil at the impropriety of assuming the division of an atom, which, according to its derivation, *α τεμνειν*, cannot be *divided.* We accept the term as a poetic licence of most innocent description; and as not by any means disturbing the beautiful train of reasoning which M. Dumas has exposed to our gaze. Had the term equivalent been used all verbal objection would have ceased.

"There are floods in the region of philosophic speculation, no less than in the commoner affairs of men. There was once a flood of alchemical aspirations: since then there has been a flood of counter operations so strong, so violent, so overwhelming, that he indeed must be a venturous man who would stand up against it. Very few people would have dared to enunciate the speculations that M. Dumas has propounded with regard to the transmutation of bodies; very few could have done it, for fear of overstepping that little demarcation which stands between the ridiculous and the sublime; but M. Dumas having enunciated *his* speculations, Dr. Faraday comes forward and says not only has *he* dreamt and thought, but tried experiments at transmutation, and professes himself so delighted with the doctrines of M. Dumas that he will, if his life be spared, try again.

"Leaving the triad of chlorine, bromine, and iodine, M. Dumas next took up for the purpose of investigation a second triad, of sulphur, selenium, and tellurium; bodies which all chemists know to be isomeric—or capable of replacing each other n compounds, and to be endowed with properties mutually analogous. Of the three, sulphur is the most volatile, selenium next, tellurium least of all. As to their decomposing power, sulphur replaces selenium; selenium, tellurium; in short, the remarks already applied to the trial of chlorine, bromine, and iodine will apply here.

"Do the generalisations of M. Dumas apply? We will see.

"The atomic or combining weight of sulphur is 16; of tellurium 64; the half of the sum of these extremes is the number 40:—and this is the exact atomic weight of the middle term of the triad—the atomic weight of selenium!

"Take, again, the triad calcium, strontium, and barium. Without stopping to indicate the various analogies of these bodies, it will suffice to point out their general chemical similarity. In this scale of analogous qualities calcium and barium are the extremes, strontium is the mean. The atomic weights of the three are as follow:—

Calcium,	20.
Strontium,	44.
Barium,	68.

And it will be evident at a glance that there is here a harmony between the chemical qualities and mathematical exponent of their combining proportion as before; for 68 plus 20 divided by 2 is equal to 44, the atomic number of strontium. Thus, if, to use the expression of M. Dumas, by any means we could effect the union of half an atom of barium with half an atom of calcium, we should have as a resultant one atom of strontium!

"Let us take now another triad:—

Lithium,	7.
Sodium,	23.
Potassium,	39

The similarities between the properties or these bodies is too evident to be pointed out; of the three, lithium is the least individualised alkaline metal; potassium the most individualised; sodium, as all know, stands intermediately between the three; and here again, as the most casual examination will demonstrate, the same parity of chemical and mathematical symmetry holds good.

"Now, so extraordinary a symmetry of chemical qualities with mathematical exponents can scarcely be assumed to be a matter of chance; still less can it be said that the atomic figures on which these deductions are based have been strained to suit the opinions of M. Dumas. Before an atomic quantity becomes classical, it is exposed as we all know, to the rigorous scrutiny of many independent chemical tribunals. If, then, exception be taken to the theory of M. Dumas, this exception cannot be allowed to extend to his facts. In theory all may err, and M. Dumas amongst the rest; we confess, however, we are not so paralysed by standing opinions as to fear to think with him.

"Hitherto we have followed the philosopher through his excursion among inorganic triads. We will now attend him further still into the recesses of chemical philosophy. It will be familiar, we doubt not, to most of our readers that many chemists, M. Dumas amongst the number, have regarded certain bodies of compound nature as analogous in many properties to the metals.

"Of this kind are the three organic radicals:—

$$\begin{array}{l} C_2\ H_3\ O \\ C_4\ H_5\ O \\ C_6\ H_7\ O \end{array}$$

which may be regarded as three several oxides of an isomeric triad, bearing analogy to those already adverted to in the inorganic world. Now, the slightest examination here will prove again that the law hitherto applied holds good in this case. Omitting the oxygen in the three preceding substances, half the sum of the extremes will be equal to the mean. Indeed M. Dumas sees in these manifestations a general law, which may be thus expressed:—when three bodies having qualities precisely similar, though not identical, are arranged in succession of their chemical powers, there will be also a successive arrangement of mathematical powers, indicated by the respective atomic numbers of the substances; and amenable to every mathematical law.

"That this symmetry of chemical with mathematical function points to the possibility of transmutation is unquestionable—yet not transmutation in the sense of the old alchemical philosophy. Chemists see no manifestations of a tendency of being able to convert lead into silver, or silver into gold. These metals are not chemically conformable. One cannot take place of another by substitution. They do not form an isomeric group. The probability is that our first successful transmutation as regards the metals will effect the change of physical state merely without touching chemical composition; thus, already we have carbon, which, as the diamond and as charcoal, manifests two widely different states. Sulphur also assumes two forms, as also does phosphorus. Then, why not a metal? This sort of effect M. Dumas suggests will be amongst our first triumphs in the way of transmutation.

"In conclusion, M. Dumas cited in support of his theory the fact that bodies of conformable qualities were generally found in union or proximity, whether as presented by nature or formed by the agency of man.

"Thus, with iron there is associated manganese. Where nickel exists cobalt is not far off;—and in the organic kingdom, when man elaborates alcohol, there are simultaneously formed small amounts of ethereal bodies. Wherever viewed, chemistry is full of the startling coincidences now introduced to our notice for the first time by M. Dumas; and, whatever may be the difference of opinion as to the speculative notions of the philosopher, there can be no doubt that he has opened a wide store of chemical treasure."]

INTRODUCTION TO LECTURE III.

HYDROGEN—ITS SYNONYMES AND ETYMOLOGY, HISTORY, NATURAL HISTORY, PREPARATION, AND QUALITIES.

Synonymes.—Hydrogen, ὑδωρ, water, γεννειν, to generate. (Lavoisier.)

Inflammable air. (Previous chemists.)

Phlogiston.

History.—Hydrogen was first examined in a pure state by Mr. Cavendish in 1766,* before which time it had been confounded with several of its compounds, under the name of inflammable air.

Natural History.—Hydrogen exists largely diffused in both the inorganic and organic kingdoms. In the *inorganic kingdom* it is a constituent of various acids in combination—as the hydrochloric, hydrobromic, hydriodic, acids. It is also a constituent of liquids—as water and naphtha; of certain solids—as sal-ammoniac and sulphate of ammonia.

In the *organic kingdom* hydrogen is found largely entering into the composition of animals and vegetables, chiefly in the form of water and ammonia.

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* Phil. Trans. vol. lvi. 144.

PREPARATION.—*Process I.*—By the electrolysis of water, each resulting gas being separately collected. This process liberates hydrogen in the condition of absolute purity.

Process II.—By adding a mixture of one part oil of vitriol by measure, and about four or six by measure of water, to comminuted zinc or iron.

Theory of the Process.—Neither zinc nor iron are capable of uniting directly with sulphuric acid: oxide of zinc and of iron, however, combine readily. Thus, a decomposition of water is determined. Oxygen of water uniting with zinc or iron, forms an oxide of these metals respectively, hydrogen being developed. In a diagrammatic representation the decomposition may be thus expressed:—

1 Water = 9 { 1 Hydrogen = 1 ——— △ is evolved
1 Oxygen = 8 } 1 Oxide of Zinc = 42 —
1 Zinc . . . . = 34 }
1 Sulphuric Acid . . = 40 } 1 Sulphate of Oxide of Zinc = 82

Process III.—By transmitting aqueous vapour through a gun-barrel or other tube of iron heated to redness.

Theory of the Process.—The water being decomposed, its oxygen unites with the iron of the tube,—and hydrogen is evolved.

N.B.—By neither process—II. nor III.—can hydrogen gas be obtained in a complete state of purity, in either case being contaminated with a carbonaceous result. Perhaps, also, when zinc is used with a little of that metal in solution. The latter may, however, be separated by transmission through solution of potash.

Process IV.—By passing up into a tube inverted, and filled with water, a piece of potassium or sodium.

Theory of the Process.—The potassium or sodium uniting with oxygen to form potash or soda, hydrogen is liberated.

PROPERTIES.—Permanently uncondensable and aëriform—neither taste nor smell when pure. Slightly soluble in water (108 cubic inches of water dissolve at 60° F. about 1·5 inches of the gas). May be respired once or twice with impunity, but if continued is fatal. Is a combustible, but does not support combustion. Is neither acid nor alkaline,—and the sole result of its combination with oxygen is water. The lightest ponderable body in nature, being sixteen times lighter than oxygen, and lighter than atmospheric air, in the ratio of 1 to 0·0696, which latter number is, therefore, said to be the specific gravity of hydrogen. At the temperature of 32°, 100 cubic inches of hydrogen weigh 2·22756 grains. Hydrogen is usually regarded as the unit of atomic weight, and the size of its combining volume is double that of oxygen.

LECTURE III.

◆

HYDROGEN.

MATERIALS AND APPARATUS REQUIRED FOR ILLUSTRATING THE LECTURE.

Granulated zinc.
Sulphuric acid.
Water.
Taper adapted to copper wire.
Mixture of two volumes hydrogen and one oxygen in a jar standing on the pneumatic trough.
Bag and jet for blowing soap-bubbles with mixed gases.
Cavendish's eudiometer, electrical machine and Leyden jar.
Candle and oil lamp for demonstrating that water results from their combustion.
Voltaic battery and tubes for collecting oxygen and hydrogen from water decomposed.
Platinum wire to be ignited by the voltaic battery.
Apparatus for passing steam over red-hot iron and developing hydrogen.
Inverted tube filled with water, for the purpose of generating hydrogen by contact with sodium.
Spongy platinum.
Hydrogen and chlorine in tubes to be exposed to sun-light.
Bromine and hydrogen and hot wire.
Chlorine and hydrogen ready to be exploded in Cavendish's eudiometer.
Hydrochlorate of ammonia for the evolution of hydrochloric acid by contact with sulphuric acid.
Hydrochloric acid developed from salt—its properties to be investigated.
Hydriodic acid into an atmosphere of a little chlorine to show iodine.

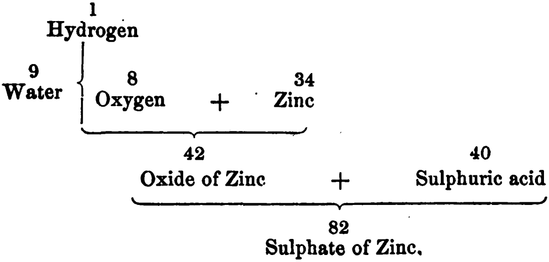
I CONSIDER it fortunate, in opening this lecture "On Hydrogen," that the arrangement of elementary bodies, as announced in the prospectus, enables me to take up hydrogen at the most convenient period for bringing prominently before your notice, and by comparison with the elements already considered, some of its most remarkable points. You are aware that it is not my object in delivering this course of lectures to present you with the complete history of the relations of the non-metallic elements, but merely to illustrate certain leading points in connection with them.

I therefore shall say nothing concerning the history of hydrogen, but shall at once bring before your notice the methods of preparing this element.

Without going into details of manipulation and apparatus, let me at once proceed, in a simple way, to show how hydrogen may be produced.

It is ordinarily evolved by adding either zinc or iron to a mixture of oil of vitriol and water.

To illustrate this process I take the metal zinc, because not only is it nearest at hand, but because the result of its action, when brought into contact with the acid mixture, is that to which my table refers:—



Putting, then, some of the metal zinc reduced to small granules into this glass flask, and adding to it a mixture of oil of vitriol and water, observe the powerful action which takes place. The liquid itself becomes disturbed as if it were boiling, and the gas escapes.

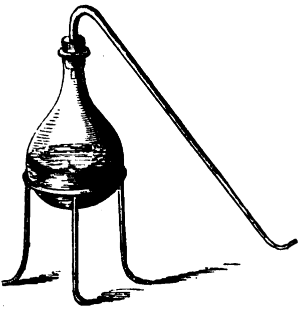
But how are you to have evidence of this escape, for there is no colour, as was the case when we were dealing with chlorine? I have an evidence of the development of hydrogen by the recognition of a peculiar smell; and if I apply a lighted taper to the mouth of the flask, then you observe a still further evidence—the gas takes fire.

But for the purpose of still further learning the properties of hydrogen, it will be necessary to collect some, which can easily be done by means of the pneumatic trough.

[The lecturer proceeded to collect some hydrogen by the usual method, and a few words respecting the manipulation of which collection may not be out of place.

The granulation of zinc, of which mention has been made, is effected by pouring melted zinc in a small stream, and from an elevation of four or five feet, into a vessel of cold water. The granulation is only a convenient means of reducing zinc to the necessary degree of comminution; and, were it not for the loss of time involved by the operation of cutting, the latter process of comminution would serve as well.

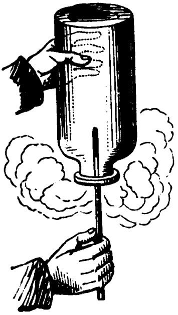
With regard to the generating apparatus, the most elegant and complete is that used by Mr. Faraday, and which consists of a glass flask having a ground orifice, into which securely fits a glass stopper prolonged into the form of a curved tube; but a Florence flask, to which a perforated cork and bent tube are attached, constitutes an apparatus which answers perfectly well; and so does a retort. Before collecting any of the gas for the purpose of experiment, it is of course necessary to allow all the first portions to escape, inasmuch as they are contaminated with the atmospheric air existing in the flask, retort, or other generating vessel.



When large quantities of hydrogen gas are required, it is usual to substitute a copper generator instead of a glass vessel. By this means the evolution of hydrogen is greatly facilitated, owing to the voltaic action which takes place between the copper and the zinc. The hydrogen gas developed when iron is made to take the place of zinc is not so pure, owing to the large amount of foreign bodies which always exist in commercial iron.]

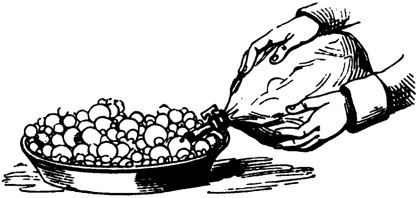
And now, having obtained several jars filled with this hydrogen, let us proceed to examine its qualities.

First, observe that I hold the jar containing it inverted, and whilst in this position, I bring a lighted taper to the mouth of the jar; and now you see an effect indicative of the presence of something different from atmospheric air. Observe, the gas at the orifice of the jar takes fire; a pale-looking lambent flame plays round the open mouth of the jar, and extends some little distance within. I now lower the jar, and bringing its open mouth flat on the table, extinguish the flame; for, observe, the phenomenon of burning can only be maintained where the gas comes into contact with atmospheric air.



If I raise the jar from the table, and apply the lighted taper once more, observe, the burning takes place a little farther up than in the previous experiment, and is attended with a sort of faint explosion. I now thrust the burning taper still further up the jar, and you observe another effect: the gas still continues to burn, but the taper flame is extinguished.

Now, combustion is one of the strongest evidences of chemical power taking place, and we have a very well-marked case of combustion here; but I will render this evidence of power still more manifest. In this jar (pointing to a jar standing over the pneumatic trough) is a mixture of two parts by measure of hydrogen with one of oxygen; there the two gases remain calm, tranquil, quiescent; transparent and colourless as the atmosphere itself, they give no indication of their power; and there, tranquil, unchanged, unacted upon, would they remain, for anything we know, to the end of time. Do not, however, imagine that mixture contains within itself no elements of power; a force of the most extraordinary kind is there—a force which, if we reduce it to a certain standard of comparison—and such standard is not wanting—will be found to equal the power of many thunder-storms. But I will give you an exemplification of this power. Filling this bag with the mixed gases, and blowing some soap-bubbles, so as to confine the gases in nothing, thus to speak, I now apply a lighted taper to the bubbles, and, observe, the result is a violent explosion. In this result we have the evidence of tremendous power. But now we come to the result of this explosion, which is water—*nothing but water.* To me, the whole range of natural phenomena does not present a more wonderful result than this. Well known now, and familiar though it be—a fact standing on the very threshold of chemistry—it is one over which I ponder again and again with wonder and admiration. To think that these two violent elements, holding in



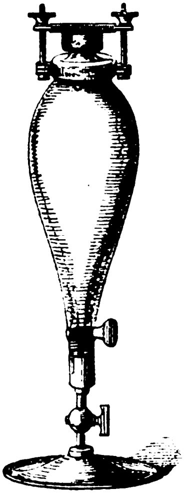
their admixed parts the power of whole thunderstorms, should wait indefinitely until some cause of union be applied, and then furiously rush into combination and form the bland, unirritating liquid, water, is to me, I confess, a phenomenon which continually awakens new feelings of wonder as often as I view it.

And now let us ponder for an instant on the leading qualities—*the points*—of water. Let us consider how widely it is distributed throughout nature—how numerous its functions—how tremendous its operations—and yet how mild, how bland, how seemingly powerless this wonderful liquid is. Let us view it in relation to the structure of living beings, and reflect how intimately it seems connected with vitality. Not only does it bathe the most delicate tissues and organs with impunity, but it enters largely into the composition of all organised forms. No structure of corporeal vitality is without it as an essential element. Water constitutes at least nine-tenths by weight of our own bodies, entering even into the very bones; yet this is but a trifling fraction of the amount of water entering into the structure of certain lower animals. Look at those delicate sea beings, the medusæ, and reflect on the vast amount of water which their structures contain! Pellucid almost as the ocean in which they dwell, these creatures float about in the full vigour of life; yet one may safely say that the medusæ consist of no less than nine hundred and ninety-nine parts water! Water in this great amount pervades their whole economy. Without much violence to language, we might call them living forms of water! Yet view these same medusæ taken from the ocean and scattered on the beach, exposed to the influence of the sun and air—their aqueous portions gone—what are the medusæ then! Shadows almost—a substance barely—the merest shred of filament and membrane!

The contemplation of this circumstance is the more strange when we consider that water, whilst in the organic structure of living beings, is continually undergoing changes, not so powerful in their manifestation, although analogous in their result to the explosion which we have seen—continually yielding up its elements to produce other forms of combination.

Water, you are aware, was considered to be an element by the ancients—an opinion which has been thought to be unreasonable and ridiculous by some; but for me, I confess my inability to see how the ancients, with the amount of evidence at their disposal, could have arrived at any other conclusion. Viewed in its relation to the universe—to its great natural manifestations—to the large range of substances into which it enters—to the manifold purposes it subserves; and, more than all, viewed in relation to its intimate connection with living forms—water does seem to present to our minds the leading qualities of an element; and it is only by the aid of chemical analysis that we prove the idea to be incorrect.

When oxygen and hydrogen unite, the result—the sole result—is water, as I have remarked, but not demonstrated. Let us, therefore, now proceed to demonstrate that fact.



This stout glass vessel, with stopper attached, through which are made to pass two wires of platinum, is so contrived that the air which it contains may be removed by means of the air-pump, and a vacuum, or at least an approach to a vacuum, formed. Screwing this vessel, now, after its air has been exhausted, upon this jar of mixed oxygen and hydrogen, in the ratio of one to two, and turning the stopcock, the water rises in the jar, as you observe—a rise which is indicative of the filling of the vessel with mixed gas. This being done, I now cause an electric spark to traverse the gaseous space between the two platinum ends, and the whole vessel becomes pervaded with light; the two gases have combined; the thick glass vessel, dry at first, is bedewed with moisture, and the moisture is water. I now turn the stopcock, and, observe, more gas rushes up; and now, passing another electric spark, we obtain another flash—another combination—another contraction of volume. I might get a third charge—a third combination—perhaps a fourth; but the continuance of this experiment would be dangerous and uncertain: dangerous, because each result of combustion heats the glass and increases its tendency to rupture; uncertain, because the amount of aqueous vapour formed would interfere with the action of the electric spark. This experiment, so conclusive as to the composition of water, we owe to Cavendish, and this thick glass apparatus bears his name.

Although this form of experiment is the most perfectly demonstrative of the composition of water, yet there are innumerable phenomena of a more simple kind which bear evidence to the same fact. Thus, for instance, if I burn a jet of hydrogen under an inverted jar the sides of the jar are speedily bedewed with a liquid, which is water; and, by continuing the experiment, water in considerable quantities may, without difficulty, be collected. Nor is a jet of hydrogen indispensable to this result; any combustible body, having hydrogen as one of its component parts, producing a similar effect. Thus, for instance, I may produce water from the combustion of a candle, just as I produced water from the combustion of hydrogen, by substituting a candle in its place; and in this way it is most interesting to see the great quantities of water thus being formed as a result of the phenomenon of combustion.*

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* This copious production of water by the combustion of hydrogen constitutes one of the great objections to gas-stoves without flues. These stoves neither smoke nor generate ill odours it is true, but the water which they generate is sufficiently considerable to prove injurious to articles of furniture, and to the human constitution in certain states of health.

[Here the lecturer showed specimens of water which had been generated from the combustion of a jet of hydrogen—a candle—a lamp, and a jet of coal gas respectively.]

We have seen that hydrogen is endowed with very great power; we have seen it occupy space, for we have generated it and measured it; its weight also has been pretty accurately determined. Let me now direct your attention to the small amount of ponderable matter which exercises this power and fills this space. You saw me hold a jar of hydrogen mouth downward, without permitting the gas to escape; you saw me, on the other hand, turn a jar of hydrogen mouth upward, and in a few instants no more gas was there. Hence hydrogen must be a very light substance; indeed it is the lightest substance of which we can take cognisance, 100 cubical inches of it only weighing 2·1318 grains; whereas 100 cubical inches of oxygen weigh 34·6. This fact of the extreme lightness of hydrogen gas enables our minds to appreciate the very wonderful circumstance of so much power existing in connection with so little ponderable matter. This to me, I confess, always seemed a point of great interest in the chemistry of hydrogen.

I have, as yet, only shown you one evidence of the exercise of this power—namely, in the phenomenon of combustion; but combustion is only, so to speak, one mode out of many by which the power may be expressed.

The next striking point to which I shall draw your attention, in relation to the natural history of water, is the fact of its being, so to speak, the only natural combination of oxygen and hydrogen—the only compound which exists ready formed, or which is generated by natural agencies; a fact which seems to be expressive of the manifold functions intended for this liquid to discharge in the economy of nature. Water, I said, might be regarded as the only compound of oxygen with hydrogen. There is another, it is true; but this compound can only be formed by refined chemical methods, and, when formed, its imprisoned elements strive to burst asunder from their artificial bondage, presenting, in this respect, a striking dissimilarity to water. But perhaps the strangest subject for contemplation, in reference to this artificial compound of oxygen and hydrogen, is the fact of its containing double the amount of oxygen which is contained by water; thus increasing our wonder for the extraordinary neutralizing force formed by hydrogen in connection with so small an amount of gravitating matter.

PER CENTAGE COMPOSITION OF WATER.

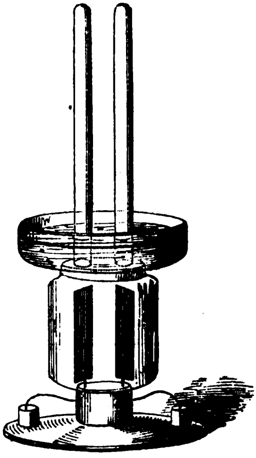
Oxygen	88·9
Hydrogen	11·1
Water	100

The relation which hydrogen bears to water I have only, as yet, demonstrated to you by the process called *synthesis*, or the demonstration of forming a compound by the union of its elements; at least, the only *plain* demonstration has been of this kind, inasmuch as the operation of obtaining water from a mixture of zinc, water, and sulphuric acid, although it liberates the hydrogen from the water, yet the source of this liberation is not directly manifest. I will now effect a similar result by employing another force—the force of voltaic electricity. These two charcoal points, which terminate each respectively a copper wire, are in connection, by means of these wires, with the ends or terminals of power of a voltaic battery; and, if any one deserved to have an apparatus stamped with his name, surely that individual was Volta. Bringing these two charcoal points into contact, you observe a vivid light is given forth; and in this light we have the evidence of the transmission of power.

I will now vary the experiment by removing the charcoal points, and attaching in their place two sheets of the metal platinum. These two sheets of platinum I dip into a little water slightly acidulated; but the acid has nothing to do with the final result. Observe the condition into which the water is thrown, being pervaded with bubbles throughout, and presenting an appearance very much resembling that which occurred when a mixture of water and sulphuric acid was added to the metal zinc. The sheets of platinum are not brought into contact, you will remark, but are at some distance from each other; yet the effect to which I directed your attention takes place.

In this result we have a proof that the water transmits a certain power, the same which you just now saw evidenced in the manifestation of heat, but now under the manifestation of chemical decomposition. By a slight variation of the experiment we can succeed in causing this power to manifest itself under the aspect of heat and of decomposition at the same time. For this purpose I substitute a wire of platinum for the copper wire just now used; and, observe, the platinum wire becomes red hot, whilst the water is driven into gas bubbles, as it was before.

I wish now to draw your attention to the fact that the gas bubbles in question are not evolved from every part of the water alike, but merely from those portions immediately in contact with each sheet of platinum; thus showing that the electric power is, by some means, and under some invisible form, transmitted through the intervening water.



Let us now proceed to collect some of the mixed gas which is being evolved — a matter of no difficulty. We have some now in a tube, and, applying a flame, you will easily recognise the mixture of oxygen and hydrogen by the flame and the slight explosion; but by a slight modification of apparatus it is not difficult to collect these gases separately, inasmuch as hydrogen is given off exclusively from one metallic plate, and oxygen exclusively from the other.

We now have the two gases separately collected, and observe that that measured amount of hydrogen evolved is almost double the measured amount of oxygen. It would have been exactly double if one small portion of oxygen were not dissolved by the water, and if another small portion did not steal round the metallic plates, and escape.*

It will be easy now to demonstrate the characters of the respective gases. Into the tube which contains the major portion I immerse, under the conditions formerly described, a lighted taper, which, you observe, is immediately extinguished, whilst at the mouth of the tube the gas itself burns. Turning now the tube mouth upwards for a few instants, and now inserting the taper once more, no such effect takes place. These manifestations are indicative of the presence of hydrogen.

Taking now the other tube, I plunge into it a chip of wood merely ignited, but not flaming. The wood immediately bursts into flame, a result clearly indicative of the presence of oxygen.

Let us contemplate now, for an instant, the marvellous result of transmitting the voltaic agency through water. This agency, setting out from the voltaic pile, we have seen to manifest itself, first, in the ignition of charcoal points; secondly, by raising to incandescence a long length of platinum wire. In these we have the manifestations of heat and light. We have seen it then made to pass through water, and with what result? Why, the elements of that fluid were torn asunder—dissevered; and this dissevering force permeates the aqueous space existing between the two metal plates in an invisible form. The effects of light, heat, and electricity, thus have been evidenced by this one experiment; and if I make a slight addition to the conducting circuit, by the interposition of a freely-moving magnetic needle, we now shall have a magnetic indication as well. In this one experiment, then, we have the voltaic force showing itself in relation with all the physical forces of nature, except the force of gravitation.

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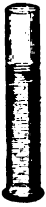
* The chemical student may be here informed that the whole theory of atomic constitution and doctrine of equivalent proportions, reposes on the basis of the composition of water by measure and by weight.

Some very curious electrical considerations arise in reference to the passage of the mysterious agency through water. Passed through a wire of platinum beyond a certain diameter, and more than a certain length, it displays no visible effect. If the diameter of the platinum wire be lessened, or its length diminished, the passage of the voltaic current is made evident by the incandescence which takes place. But the wire undergoes no permanent change; when cold it is the same as it originally was. How different the result with water! Through this the agency can only pass, as we have seen, by tearing the elements of the water asunder. And if water be changed from the fluid to the solid condition, if, in other words, it be converted into ice, then the electric influence, whatever it may be, is incapable of passing at all. The current is no less utterly and absolutely intercepted than if the icy portion of the circuit were entirely removed.

There are other plans of evolving hydrogen in addition to those already shown; and of these I will now select the two principal ones, for the purpose of still further demonstrating the relation in which hydrogen stands to water.



Taking this narrow glass jar, filling it with water, and inverting it thus filled over the shelf of the pneumatic trough, I now pass up into it a globule of the metal sodium. Already you have had your attention directed in a former lecture to the affinity manifested by sodium for oxygen, an affinity on which the evolution of hydrogen in this case depends: the sodium uniting with oxygen to constitute soda, which is soluble in water, whilst the hydrogen assuming a gaseous condition is evolved. The last plan of obtaining hydrogen, to which I shall direct your attention, consists in the forming of watery vapour or steam through a red-hot iron tube. In this case the iron acts in a similar manner to the sodium—that is to say, it combines with oxygen, and liberates the hydrogen in a gaseous state. No more processes for the generation of hydrogen I shall bring before you; but, if time permitted, I could direct your attention to many other curious points in connection with its chemical affinities and tendencies. One is so extraordinary, so beautiful, that I cannot allow it to pass without making it the subject of explanation and experiment.

Unlike chlorine, which displays an immediate violence of combination, without the interposition of any promotive cause—unlike oxygen, which assumes an intermediate state of activity in the condition of ozone—hydrogen waits until the application of some combining cause brings suddenly, and at once, its tremendous activity into play; yet it is subject, nevertheless, when in contact with oxygen gas, to assume the strange chemical affection termed catalysis, and of which I will show you some examples. Attached to this platinum wire is a portion of the same metal in a finely-divided state, to which the term platinum sponge is applied; and this platinum sponge I will now insert into an inverted jar of mixed oxygen and hydrogen gases. The platinum sponge becomes soon red hot, and now, observe, the gaseous mixture explodes. Again, if I apply the same piece of platinum sponge to a jet of hydrogen, as it issues from a vessel containing it, the gas speedily bursts into flame.

Concerning the theory of this beautiful phenomenon we are ignorant; the gases are made to combine, yet the platinum remains unchanged. True, the expression catalysis has been applied to this phenomenon; but names are not knowledge. I want to know why this beautiful exercise of power takes place. I want to know how it is—by virtue of what agency—these two quiescent gases in their tranquil, passive, waiting state, at once rushed into combination so soon as this little fragment of metallic sponge was immersed. Of this we are ignorant still; but if I may be permitted to express a view on the cause of this result, I would hazard the opinion that the metallic sponge serves as a conductor of electric influences between the two sets of gaseous particles. It is only an opinion, but one which seems to me not altogether divested of probability.

Although, considered under the aspect of its general distribution and importance, no hydrogenous compound can compare with water, yet there are others which must not be passed over. It combines with chlorine, bromine, and iodine, the elements discussed in our preceding lecture; forming respectively with each one acid compound. In the case of chlorine we have resulting the hydrochloric or muriatic acid; of bromine, the hydrobromic; and of iodine, the hydriodic acids. All these substances may be formed by direct union of the respective elements; although in practice on the large scale they are made in another way.

Directing our attention first of all to hydrochloric acid, we shall find that if equal measures of chlorine and hydrogen be mixed together, in a glass tube, no combination ensues in the dark. Solar light causes the two, however, to unite; and if the light be not diffused—that is to say, if it be the light of direct sunshine—the union is accompanied by an explosion. The passage of an electric spark through this mixture of hydrogen and chlorine in equal volumes, causes a similar union to ensue; and may readily be accomplished by means of the eudiometer of Cavendish.

By a modification of this treatment also, the vapours of iodine and of bromine may also be caused to unite with hydrogen; in which case hydriodic or hydrobromic acid results.

In procuring these acids, however, in practice, indirect processes are had recourse to. The materials for generating hydrochloric acid are chloride of sodium (common salt), sulphuric acid, and water, all of which being distilled together, hydrochloric acid results, and sulphate of soda is left. In this operation the chlorine of the acid is yielded by the chloride of sodium, and the hydrogen by the water.

Hydrochlorate of ammonia (*sal ammoniac, chloride of ammonium*), may also be employed instead of common salt for the generation of hydrochloric acid; sulphuric acid being employed as the decomposing agent.

The usual process, however, of generating hydrochloric acid is the former—namely, by mixing together common salt and commercial sulphuric acid; which is a hydrate of the real acid, or a compound of it with water. Hydrochloric acid in its uncombined state is a colourless, acid, irritating gas, possessing so remarkable a tendency to unite with water, that it cannot be collected in a trough containing that liquid.

Hydriodic and hydrobromic acids cannot be generated in this manner, a still more indirect process of formation being necessary; but the results when obtained manifest a complete analogy between all three.

Thus hydrogen unites with chlorine, bromine, and iodine, forming three acid bodies, having very striking analogies; the force, however, wherewith it combines is not the same in either case. Thus, for instance, if chlorine be passed into hydriodic or hydrobromic acid gas, decomposition ensues, hydrochloric acid gas is formed, and iodine or bromine set free.

But it is not so much for the purpose of indicating the chemical reactions of these substances that I mention them, as to point out the remarkable significance of their atomic or combining weights. Here is hydrogen, the lightest known ponderable substance in nature, combining with chlorine in the ratio of one part by weight to 36, with bromine in the ratio of one part by weight to 80, with iodine in the ratio of one part by weight to 125; satisfying the affinity of combinating in either case, generating powerful acids, and presenting an equality of force as measured by electrical decomposition; how great then is the active power of hydrogen in relation to its combining weight! This is one of the great features—one of the prominent characteristics—the "*points*," of hydrogen, to which I especially wish to direct your attention.

And now time admonishes me to be brief. I might go on illustrating farther points of interest possessed by this beautiful element; but I must conclude. The chief features, the distinctive points of hydrogen, are, as you have seen, the exteme powers of combination with which it is endowed, associated with so little ponderable matter; the force of its combining agency with oxygen; the stability, the blandness, the extensive distribution, and manifold uses of water, the result; its intimate association with organic structures, and thence the relation it seems to have with every corporeal living form; and, lastly, the tranquil placidity of its waiting condition until, by flame or electricity, or catalysis, it is caused to unite.

HYDROGEN—ITS WEIGHT AND SPECIFIC GRAVITY.

	gr.
100 C. I.	2·1318
To Air	0·0694
Hydrogen	1

To me this waiting state of elements is one of the most beautiful topics of philosophic contemplation. When I consider the multitude of associated forces which are diffused through nature—when I think of that calm and tranquil balancing of their energies which enables elements, most powerful in themselves, most destructive to the world's creatures and economy, to dwell associated together, and be made subservient to the wants of creation,—I rise from the contemplation more than ever impressed with the wisdom, the beneficence, and grandeur, beyond our language to express, of the Great Disposer of all!

INTRODUCTION TO LECTURE IV.

NITROGEN—ITS SYNONYMES AND ETYMOLOGY, HISTORY, NATURAL HISTORY, PREPARATION, AND QUALITIES.

Synonymes and Etymology. — Nitrogen, *νιτρον*, Nitre; *γενναω*, I form:—Azote, *α*, priv., *ζωή*, life. (Lavoisier.)

Mephitic air.—A term not only applied to nitrogen, but to other gases which are deleterious to life.

Phlogisticated air. (Priestley.)

History.—This element was first recognised as distinct from all others by Dr. Rutherford in 1772. (Thesis de Aëre Mephitico.)

Natural History.—Nitrogen is found both in the inorganic and organic kingdoms. As a constituent of the inorganic kingdom, we have it (1) in the atmosphere, of which it constitutes four-fifths; (2) as a constituent of ammoniacal salts; (3) as a constituent of coal beds; (4) as a constituent of nitrates of soda and of potash—salts which are extensively diffused in some parts of the world. In the organic kingdom nitrogen especially characterises animal, in contradistinction to vegetable, beings; nevertheless it is found in the latter, but in small quantities. The natural orders cruciferæ and fungaceæ are amongst vegetables especially rich in nitrogen. Inasmuch as animal beings contain so much nitrogen, and vegetables so little, Berzelius has imagined that nitrogen is generated in some unknown manner by the animal functions. This idea, however, has been opposed by Liebig, who, with the majority of chemists, believes that the nitrogen existing in plants is sufficient to account for the large quantities of that element locked up in the tissues of herbivorous, no less than other animals.

Preparation.—(1) By the combustion of phosphorus in atmospheric air; the result of which is the formation of phosphoric acid and the liberation of nitrogen.

DIAGRAMMATIC ILLUSTRATION OF THIS DECOMPOSITION.

$$\begin{array}{ll}\text{Atmospheric air} & \left\{\begin{array}{l}\text{Nitrogen}\underline{\hspace{6cm}}\triangle\text{ is evolved.}\\ \text{Oxygen}\left.\begin{array}{l} \\ \\ \end{array}\right\}\text{ Phosphoric Acid.}\end{array}\right.\\ \text{Phosphorus}\;.\;\;.\;\;. & \end{array}$$

(2) By transmitting chlorine through a solution of ammonia: chlorine uniting with hydrogen to form hydrochloric acid, which combining with undecomposed ammonia, hydrochlorate of ammonia is formed, whilst nitrogen escapes.

DIAGRAMMATIC ILLUSTRATION OF THIS DECOMPOSITION.

1 Ammonia = 17 { 1 Nitrogen = 14 ———— △ is evolved.
1 Ammonia = 17 { 3 Hydrogen = 3 } 3 Hydrochloric acid = 111
3 Chlorine . . . . . = 108 } 3 Hydrochloric acid = 111
3 Hydrochloric acid = 111 } Hydrochlorate of ammonia = 162
3 Ammonia . . . . = 51 } Hydrochlorate of ammonia = 162

(3) By agitating a liquid amalgam of lead and mercury with atmospheric air for two hours or more,—the result of which is absorption of oxygen and liberation of nitrogen.

(4) By mixing iron filings and sulphur with water, and exposing the mixture to atmospheric air for the space of forty-eight hours. In this, as in the preceding case, atmospheric oxygen is absorbed and nitrogen set free.

(5) By exposing muscle (flesh) to the action of nitric acid in a retort to which heat is applied. The theory of this decomposition is exceedingly complex, and cannot be satisfactorily explained.

PROPERTIES.—Nitrogen is permanently elastic and colourless. It has neither taste nor smell, does not act upon vegetable colours, nor does it whiten lime-water. By this latter characteristic especially it is distinguished from carbonic acid. It is neither acid, nor alkaline, neither supports combustion nor burns,—although its chemical relations impart to it some claim of being regarded a combustible. Water which has been boiled absorbs it to the extent of one and a half per cent. Its refractive power is rather greater than that of atmospheric air (1·0340 to 1) and 100 cubic inches of it at mean temperature and pressure, weigh 30·16 grains ; hence its specific gravity is 0·972, as may be thus deduced :—

Wt. of 100 c. inches of Air.		10 c. in. Nitrogen.		Unity.		Sp. gr. Nitrogen.
31·0117	:	30·1600	: :	1	:	0·972

Or, seeing that the atomic weight of nitrogen is = 14, and its atomic size = hydrogen or □, its specific gravity may be deduced by multiplying the specific gravity of hydrogen (0·0694) by the atomic weight of nitrogen (14).

LECTURE IV.

◆

NITROGEN.

APPARATUS AND APPLIANCES EMPLOYED IN THE FOLLOWING LECTURE.

Apparatus for the combustion of oxygen in a jar over water, so that oxygen may be separated from the air, and nitrogen left.
Nitrogen already collected and washed.
Nitric acid.
Tin foil.
Copper turnings.
Litmus paper.
Iodide of nitrogen.
Ammonia.
Evolution of ammonia, from sal-ammoniac and quick-lime.
Various bottles of ammoniacal gas.
Prussic acid.
Apparatus for developing cyanogen.
Nitrous oxide gas.
Nitric oxide gas
Nitrous acid gas.
Nitric acid.
Apparatus for developing hydrogen from zinc.
Nitre.
Mixture of two volumes nitric oxide gas and five volumes hydrogen platinised asbestos, and tube.

THE element Nitrogen, which I purpose bringing before your notice this day, is one of exceeding interest, under whatever aspect viewed. Whether we have regard to the enormous amounts of this element which pervade nature, or the importance of the functions to which it is made subservient, the curious chemical affections with which it is endowed, the number and various conditions of its numerous compounds, or the apparent paradox of the most violent combinations resulting from an element which, in its simple state, is characterised by a quality of inaction or passiveness:—all these are considerations which bespeak our interest, in an eminent degree, for nitrogen.

But I am proceeding in anticipation of my subject: you have not yet seen or had other physical manifestation of this element of which I speak,—element I still must call it, although nitrogen is endowed with many qualities which lead one almost to imagine that it is really a compound.

The usual method of obtaining a supply of nitrogen for the purpose of experiment, consists in extracting it from the atmospheric air; or, I should rather say, in extracting from the atmosphere—oxygen, the associate of nitrogen; thus leaving the nitrogen isolated or alone.

COMPOSITION OF ATMOSPHERIC AIR.

	Bulk.	Weight.
Oxygen . . .	20	22·3
Nitrogen . . .	80	77·7

For this purpose we avail ourselves of the strong combustive powers of phosphorus; which, when ignited in a closed measure of atmospheric air, removes all the oxygen in the condition of phosphoric acid, and sets nitrogen free.

The experiment is most conveniently performed by putting a small metallic capsule to swim on a surface of water, in the pneumatic trough, igniting the phosphorus by means of a hot substance, and when ignited, inverting over it a bell glass, or receiver of atmospheric air. The phosphorus continues burning as long as any oxygen remains; the bell glass becomes pervaded with dense vapours; the water rises in proportion as the combustion advances; and finally, when the phosphorus ceases to burn, it may be known that the oxygen has been entirely, or almost entirely, removed. The gas, thus prepared, and at present admixed with the vapours resulting from the combustion of phosphorus, is to be washed by transference from one jar to another, until it becomes transparent and colourless. It is now nitrogen. Having transferred some nitrogen, thus prepared, to a smaller jar, for the purpose of experiment, let us examine its qualities. That it has no colour is evident to all; and to me the fact is evident that nitrogen is devoid of smell. In these respects it is very different from either of the elementary bodies I have already brought before your notice, except oxygen. Oxygen, however, as you will remember, has very powerful affections with regard to ignited bodies, causing them to burn much more vividly than in the atmospheric air: let us see whether nitrogen is endowed with properties which are similar. Plunging an ignited taper into this jar of nitrogen, you will observe that the taper, instead of burning more vividly, as it would have done in oxygen, is extinguished; and thus already have we succeeded in the attempt of individualising nitrogen from all the other substances which I have brought before your notice.

For the sake of still further adding to our list of facts indicative of the qualities of nitrogen, I plunge into a bottle containing it, a strip of turmeric paper, moistened, which is the common test of alkalinity; and, as you observe no change takes place, I now remove the moistened turmeric paper, and insert a strip of moistened litmus paper, which is a test for acidity, in its place; still you observe no change of the paper results.

In this way might I go on applying various tests to the jar of nitrogen, and I might demonstrate that not only is it devoid of colour, of taste and smell, of alkaline and acid properties—not only will it neither burn nor support combustion, but that a much longer list of negative qualities might be found. It does not support animal life—does not whiten lime-water, by which means it may be distinguished from another gas; nor does it, otherwise than in a few exceptional cases, enter into direct combination with other bodies.

In illustration of this non-combining quality of nitrogen, except under indirect circumstances hereafter to be mentioned, I may mention the fact that, according to Dr. Percy, no less than six tons of air pass through an average-sized iron blast-furnace every hour, during which transit the oxygen part of the air is most active in forming combinations, yet the nitrogen, although subjected to precisely similar conditions of heat and contact, emerges, as it entered, uncombined. In making this statement, I do it generally, so as to express a fact in its broadest aspect; not taking cognisance of some combinations of nitrogen, trifling in amount and questionable in their nature, which, according some authorities, are, under these circumstances, formed.

Yet, do not fall into the error of regarding nitrogen in the light of a mere diluent, unendowed with chemical affections, or tendencies to combination; such an idea would be totally at variance with actual conditions, would totally misrepresent one of the leading features, or *points*, of nitrogen, which consists in the variety, and generally the power and energy of its combinations when placed under circumstances which are favourable to their development.

It is a quality of nitrogen to avoid direct combination with elements; its combinations with them result from the agency of indirect, oblique, or circuitous processes, which conditions being accorded, we frequently see whole lists of substances springing into existence,—whereas, in the case of hydrogen, the combining tendency was satisfied by the formation of one or two.

In illustration of these indirect combining tendencies manifested by nitrogen, I must here slightly anticipate my subject of discourse for the purpose of introducing to your notice a very remarkable compound; illustrative, by the mode of its formation, of the peculiarly oblique processes demanded by nitrogen for calling its powers of combination into play—illustrative, by the marked instability of the union of its elements, of the frail, forced, and, so to speak, fleeting union into which the nitrogen has been constrained.

Here is the elementary body, iodine. I may expose it to the atmosphere, which contains nitrogen; I may expose it to gaseous nitrogen unmixed for an indefinite period, without the development of any result, save that of evaporation. A portion of the iodine, being volatile, goes off in fumes—no more. There is no combination.

Yet, to infer that no combination of the two is possible — that no tendency to combine exists from what we have seen, would be most incorrect. If the iodine and the nitrogen be brought within the sphere of each other's affinity by a peculiar indirect course, then combination readily, almost immediately, ensues; the result being iodide of nitrogen;—the substance now standing in little separated masses on the bibulous paper before me; not these large brown stains, but the small collection of dark substances, not unlike iodine itself, but somewhat blacker, which is seen in the middle of the stains, That substance is the iodide of nitrogen—a substance of very peculiar qualities, as we shall presently see. And here whilst speaking of the iodide of nitrogen, I may interpose the remark, that no person, from mere consideration of the qualities of substances in their separate state, would predict the qualities of the result of their combination. This iodide of nitrogen is endowed with a quality highly dissimilar to any possessed by either iodine or nitrogen in themselves, a quality which would not have been predicted, or even guessed at; and in this, and many other instances, are all our previous speculations as to the qualities of unknown bodies disproved by actual facts. Thus, in relation to potassium and sodium it was no sooner found that these bodies were violently attractive of oxygen—abstracting it with avidity, even from water and the air—than it was assumed forthwith that the same quality must attach, as of a necessity, to silicium, or silicon, the basis of silica, or flint, should this substance ever be isolated. Well, it has been isolated, and no pre-eminent quality of this kind attaches to it. It may be left for years together in air or water without undergoing perceptible change.

But I have diverged from the subject of iodide of nitrogen. I commenced by telling you that the two elements refused directly to unite—requiring for the development of this union some indirect process of treatment. I did not show you the indirect process. There is a compound which I shall have to mention presently, which consists of three atoms or equivalents of hydrogen, in union with one of nitrogen; the compound is ammonia. Naturally in its uncombined state it is a gas, but it is readily, even violently, absorbed by water, and when so absorbed, it constitutes liquid ammonia, or hartshorn.

CAPACITY OF SOLUTION OF AMMONIA IN WATER.

	Volumes.
Ammonia	0·670
Water	1
Specific gravity of solution	0·875
Bulk of solution	1·68

Now, iodide of nitrogen is generated by bringing liquid ammonia into contact with iodine for a short period, then filtering off, and drying by exposure to air, on filtering paper, the black result, which is the iodide of nitrogen in question. In this substance the nitrogen is confined by so small an excess of force, that the merest friction between its particles is sufficient to shatter it into the two elements of which it is composed. This exceeding instability of composition I can illustrate by projecting it upon the surface of cold water, with which, immediately it comes into contact, an explosion takes place.

COMPOSITION OF THE CHLORIDE AND IODIDE OF NITROGEN.

N	C	C	C		
14	36	36	36	=	122
N	I	I	I		
14	126	126	126	=	392

In whatever direction we look over the widely expanded range of chemical phenomena, we continually find nitrogen manifesting itself under the same quality of combining power—displaying the same tendency to indirect union. Yet the compounds into which it enters, so far from being few or trivial, are most numerous; and so far from being unimportant, they are associated in some mysterious way with all the higher forms of animal existence. The blood, the muscle, the brain, the nerves of animals, all contain nitrogen to a large amount, from which the nitrogen may be readily separated—not as nitrogen but ammonia.

I have here before me the materials for generating ammonia, as also various jars already filled with the gas. It will be more convenient, however, for some reasons, that the consideration of this substance should be deferred until the acid combinations of nitrogen with oxygen shall have been brought before your notice.

Nitrogen, you have seen, exists in admixture, if not in combination with oxygen to constitute atmospheric air. Every five volumes of air contain in this way four volumes of nitrogen, and the result is, so far as we know, the only mixture which can sustain the functions of vitality and the economy of the world. With regard to the mode in which nitrogen is associated with oxygen in the atmosphere, this is usually said to be mechanical. At any rate the compound substance is not endowed with those new qualities which usually result from chemical unions, but presents merely a mean resultant of the qualities manifested by oxygen and nitrogen individually. Far otherwise is the case in respect of the other associations of oxygen with nitrogen, of which there are no less than five.

TABLE SHOWING THE PRESUMED GROUPING OF ELEMENTS IN VARIOUS NITROGEN COMPOUNDS, AND THE DIFFERENCE IN QUALITY EFFECTED BY COMBINATION.

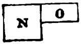
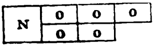
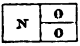
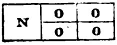
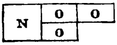
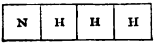
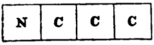
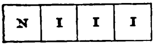
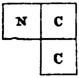
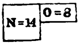
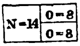
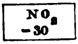
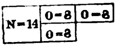
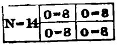
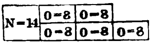
	Gas, inodorous, sweet, inactive
	Liquid, acid, colourless, corrosive.
	Gas, colourless, not acid, insoluble, oxidising.
	Gas or liquid, coloured, acid, soluble.
	Liquid, acid, unstable.
	Gas, alkaline.
	Liquid, detonating.
	Solid, detonating.
	Gas, combustible, odorous, poisonous.

TABLE SHOWING THE COMPOSITION BY WEIGHT AND MEASURE OF THE COMPOUNDS OF OXYGEN WITH NITROGEN.

	form by union		Protoxide of nitrogen, nitr*ous* oxide, or laughing gas.
	form by union		Binoxide of nitrogen, or nitr*ic* oxide.*
	form by union	38 volume unknown	Hyponitrous acid.
	form by union		Nitrous acid.
	form by union	52 volume unknown	Nitric acid.

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* The atomic volume of this gas is double that of hydrogen.

All of these are endowed with newly-begotten qualities, so marked, so powerful, so well defined, that the original attributes of oxygen and of nitrogen are totally lost. Thus anticipating a little my description of the first compounds in the list, let me direct your notice to this powerful and highly useful combination of nitrogen with oxygen, nitric acid, or aquafortis. Dissolved in water, as I have it here, it is a straw-coloured fluid; endowed with agencies so violent, so numerous, so readily called into action, so direct, that in these respects it presents the greatest possible contrast to nitrogen. The violent qualities of reaction presented by nitric acid, enable it not only to attack the greater number of dead inorganised substances, but also living tissues. Of this latter quality, chemists who are in the habit of much employing this acid experience a proof in the yellow colouration, going on to destruction, of those portions of the skin with which nitric acid may come into contact. I will not perform the experiment in that way, but I will substitute for the fingers a piece of parchment,—and you will observe as soon as I touch it with nitric acid how contracted and shrivelled it becomes. Equally well would the same destructive agency, the same shrivelling up, have been exercised on a living piece of skin.* As illustrations of the power of nitric acid over the substances generally, of the inorganic kingdom I need not look farther for examples than the cases afforded by pouring the acid over tin and copper respectively. In either case you observe a violent reaction take place; in either case you observe red or orange coloured fumes evolved; but when tin was employed, a white insoluble residue remains, whereas when copper was employed there resulted a solution. Great are the chemical powers of nitric acid, manifold the uses to which it is applied; but on these I shall not linger, my object not being to give you a detailed exposition of these matters.

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* It is an extraordinary, very cruel, and too common experiment among physiologists to illustrate what they are pleased to call a power of vital contractility under the influence of a stimulus, by touching with a glass rod, dipped in nitric acid, the

I commenced my notice of the compounds of nitrogen by introducing nitric acid, because of its falling naturally in with the current of my discourse, and because of its great importance; you will see, however, by casting your eye at the table of compounds of nitrogen and oxygen, that other substances stand before it, if we have reference to the numeral equivalent of oxygen with which the nitrogen is combined. The first compound indicated by the table is a compound of one volume nitrogen with half a volume of oxygen; this compound I have here before me in the shape of a colourless gas. It is the protoxide of nitrogen, or nitrous oxide—sometimes

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heart of a living rabbit. In an instant the heart shrivels up and contracts to one-third its original size. The experiment is well worth seeing for once, and may be performed without cruelty by stunning the rabbit with a blow on the head previous to opening the thorax and displaying the heart.

called the laughing gas, owing to the curiously exhilarating effect it produces when breathed. This gas is generated by the distillation of nitrate of ammonia, and affords another instance of a nitrogenous body being produced by an indirect agency.

This gas has a sweet taste, if one may be permitted the application of this expression to a gas,—and its physiological effects probably having been made familiar to you, I will proceed to draw your attention to a circumstance illustrative of the accurately-adjusted balance of powers by which all created things are adapted, each to the fulfilment of its own peculiar end.

Not long since I remarked, that of all the associations of nitrogen with oxygen, none, so far as we knew, could discharge the functions of the atmosphere. Now here is a gas which may be breathed with impunity for a short time, but if the time of inspiration were to be prolonged, death would inevitably ensue: here, then, in one great necessity of the atmosphere, the nitrous oxide is deficient. Let us now try it in reference to combustion. Judging from the great amount of oxygen which it contains in comparison with atmospheric air, one might infer that this protoxide of nitrogen would be a better supporter of combustion than the atmosphere: this inference is not correct, absolutely. It is a better and it is a worse supporter of combustion than atmospheric air; but it is necessary that I explain; which explanation will best be accomplished by means of experiment. On plunging a taper already lighted into a jar of this gas, you will observe that the taper burns with much more brilliancy than in the atmospheric air; hence, so far as this experiment furnishes us with evidence, nitrous oxide is a better supporter of combustion than atmospheric air. But if, instead of the taper, a fragment of phosphorus, only just ignited, be inserted,—ignited to an extent that would cause it to burst into rapid combustion were it allowed to remain in the atmospheric air,—then, under these conditions, the phosphorus is extinguished; a circumstance which illustrates my expression of the gas in question being a worse supporter of combustion than atmospheric air. If now, varying the experiment slightly, the phosphorus be fully ignited, and then plunged into the gas, rapid and exceedingly vivid combustion supervenes: —a result which shows that the power of supporting combustion is there, but that it is only brought into operation under the association of certain conditions. It will be easy to recognise, therefore, for the evidence of these experiments, that nitrous oxide gas would have been totally unfitted to stand vicariously for the atmosphere.

Next in the list of substances resulting from the combination of nitrogen and oxygen, as shown by the table, comes the binoxide of nitrogen, a gaseous substance containing twice the amount of oxygen held in union by the former. Like the protoxide, you will observe it is colourless whilst confined in a closed vessel, as this bottle for instance; but it is different from the former, not only in composition, but in its manifestations. Thus, if I remove the stopper of a bottle containing this gas, you will immediately see the portions of it which come into contact with the atmosphere change colour. This arises from the formation of two new substances, hyponitrous and nitrous acid, mixed together in varying proportions. These substances result from the combination of the binoxide with more oxygen; let us see, therefore, what the result will be of mixing some of the binoxide, not with atmospheric air, but with pure oxygen. In this jar, standing over the pneumatic trough, is some pure oxygen, and into it I pour some of the binoxide of nitrogen, standing in another jar: you observe the intense orange vapours which result,—much more intense than when we mixed atmospheric air with the binoxide: and you will also observe how rapidly the orange vapours thus produced are absorbed by the water. On account of the orange-red vapours thus developed in bringing binoxide of nitrogen in contact with the atmospheric air, or oxygen, or, generally, any gas containing oxygen, the two remaining gases become mutually tests for each other: the appearance of red vapours on the admixture of binoxide of nitrogen with any unknown gas being indicative of the presence of oxygen.

The general tendency of all the series of oxygen compounds with nitrogen, is towards acidity; and, in the three last compounds mentioned, namely, hyponitrous, nitrous, and nitric acids, the quality of acidity is very highly developed. The test for general acidity is either tincture of litmus or litmus paper. If I take a slip of the latter, and hold it in the orange fumes, composed of hyponitrous and nitrous acid, the paper immediately reddens, thus proving the existence of acid qualities in them. Let me now demonstrate the extreme acid properties of nitric acid. For this purpose, I drop just two drops into about half a pint of water; and now, plunging a slip of blue litmus paper into this acidulated water, and withdrawing it, observe how marked is the change of colour to red, which takes place. The paper so treated let us preserve, for the purpose of applying it to another case of testing, by and by.

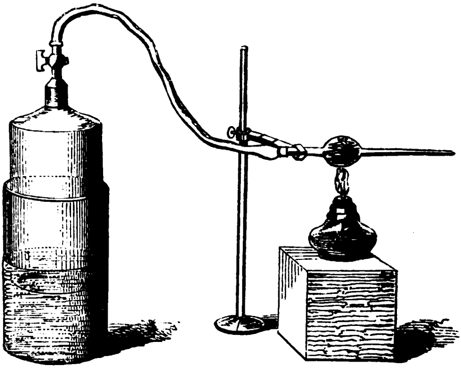
Leaving now the combinations of nitrogen with oxygen, let us turn our attention to the combination of that substance with hydrogen, of which there exists but one; at least, but one which can exist in the isolated or non-combined state, although the existence of two others has been inferred by the adoption of hypothetical trains of reasoning. This one compound of hydrogen and nitrogen is ammonia, a substance which, in its uncombined condition, is a gas, endowed with very remarkable properties: remarkable if considered as regards itself alone, but still more remarkable if studied in comparison with the powerfully acid bodies containing nitrogen, which we have just passed in review.

Nitrogen, I have already remarked, is a constituent of all the higher forms of corporeal vitality, being essentially connected with the existence of animal life, and pervading also to a great extent the constitution of vegetables; for this reason it has been denominated by some writers a zoogen. Thus it enters as a main constituent into muscle, brain, and nerves, from all of which it may be evolved by proper treatment; not readily in the form of nitrogen uncombined—but ammonia.

If a little isinglass, or dried skin, or almost any animal tissue, except fat, be heated in a retort, or other adequate vessel, to an extent sufficient to effect what is termed by chemists destructive distillation—ammonia, in admixture with certain volatile yet condensible results, comes over.

For the purpose of experiment, however, I shall not develop it from this source, but from the hydrochlorate, or muriate of ammonia (*syn.* sal ammoniac, or chloride of ammonium). This development is effected by mixing the salt in question with a little quick lime, and adding a slight amount of water, just sufficient to slake the lime. I effect this admixture in a glass jar, and now immersing in the atmosphere of the jar a slip of turmeric paper, moistened with water—observe the original yellow colour of the turmeric changes to reddish brown. This is the common test of alkalinity. There is another test, the result of the action of ammonia, one which will still more prominently demonstrate the contrariety of quality manifested by this substance in reference to the acid combinations of nitrogen with oxygen. Taking the slip of litmus paper, reddened by immersion in dilute nitric acid, I will now hold it in the ammoniacal atmosphere, and observe the redness of the paper disappearing, its original blue colour returns; thus demonstrating that marvellous capability which nitrogen possesses of entering into the two opposite states of acidity and alkalinity.

Although it is a striking tendency of nitrogen to avoid all direct combination,—entering into its numerous unions by oblique or indirect processes,—yet, by means of that strange chemical influence termed catalysis, and of which mention was made in the preceding lecture, an approach towards the direct chemical union of hydrogen and nitrogen may be effected. In this jar has been put a mixture of two volumes binoxide of nitrogen and one of hydrogen, and the jar is so arranged that, by depressing it in the pneumatic trough, and opening the stop-cock, the mixed gases may be made to pass through a glass tube containing some asbestos covered with thin films of the metal platinum, and finally emerge in a jet.



I now cause the mixed gases to pass over the platinised asbestos in a cold state, and you will observe that the mixed gases, on touching the atmospheric air, become pervaded with red or orange coloured fumes. In this case the hydrogen present has counted for nothing, the binoxide of nitrogen alone having displayed its usual manifestation, yielding when brought into contact with atmospheric air a mixture of hyponitrous and nitrous acids; still further evidence of the existence of which may be gained by presenting to it a slip of moistened litmus paper, which immediately turns red.

I now apply the flame of a spirit lamp to that portion of the tube which contains the platinised asbestos, and repeat the operation; when there no longer emerge those red fumes, a fact sufficiently indicative of the circumstance that some change has taken place. In point of fact, the catalytic action established by the hot platinised asbestos has effected a combination of hydrogen with nitrogen, and generated ammonia. Hence, if I now hold opposite to the jet of gas as it emerges, the portion of litmus paper already reddened by the previous jet, the reddened portion is almost instantaneously changed back to its original blue. There cannot be a more striking exemplification of the remarkable faculty possessed by nitrogen of assuming the qualities of two opposite chemical bodies.

I shall now show you a compound of nitrogen with carbon, and which is termed cyanogen, from the part which it takes in the formation of Prussian blue.

Cyanogen is not formed by the direct union of nitrogen and carbon, but requires, as in preceding instances, an indirect method to be followed. In this small tube retort I have a little cyanide of silver, and now, applying heat, a gas very poisonous in its quality, and having the odour of peach blossoms, comes over.

We have seen nitrogen competent to the formation of acids and alkali—bodies of strongly-marked chemical qualities. Here we see it uniting with carbon to generate a body neither acid nor alkaline, but remarkable for its poisonous action and large range of intricate chemical combinations. The gas cyanogen, when ignited, burns, as you observe, with a violet-coloured flame; which characteristic, taken in connection with the peculiar smell of peach blossoms, is sufficiently indicative of its presence.

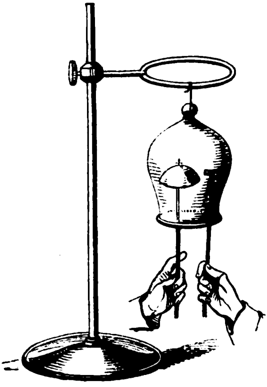
I now have to speak of a most remarkable point in the natural history of nitrogen. It is a point in connection with the demeanour of this substance to electricity, that mysterious power which, when brought into action and competently applied, obliges so many compounds to yield up their elements in obedience to the direction of its force. Water you have already seen torn asunder by electricity; its elements liberated at either terminal point of electric power; but electricity, although it seems the force destined to rend compounds into their simple elements, and marshal these elements in order pre-determined, each in its own appointed place of rest—electricity determines no liberation of nitrogen from any of its compounds; a circumstance which seems to point to the idea that nitrogen is not in itself a simple substance.

Time admonishes me to be brief, yet I must not conclude without drawing your attention to the beautiful adaptation of nitrogen to its atmospheric functions, as manifested in its specific gravity. So near is this specific gravity to the specific gravity of the associated oxygen, that the two gases mingle perfectly, and form one homogeneous whole for equal circumstances of temperature and pressure. Had there been any great difference of specific gravity, however, the result would have been different; the two gases would have separated partially, and hence such an atmosphere would have been rendered unadapted to all the functions it has to discharge. Take, for instance, the function involved in the propagation of sound. As the atmosphere is now constituted, there exists a permanency of sonorous pitch; any tone being once generated remains the same tone until it dies away. Its degree of loudness alters in proportion to the distance of the listener from the place where it is generated—but its pitch never.

PONDERABLE RELATION OF NITROGEN TO ATMOSPHERIC AIR AND HYDROGEN.

	Grains.
100 C. I.	30·16
To Air	0·976
Hydrogen	14

If, however, the atmosphere had been composed of two gases, each having widely dissimilar specific gravities, there would have been a difference. No permanency of tone could then have been depended on—the pitch of every original note would have been continually varying as its transmission might be propagated by the vibrations of ever-varying mixtures of the two gases of dissimilar specific gravities. All that studied arrangement of defined notes, which constitutes the art of music, would have been lost to us for ever, had we been enveloped by such an atmosphere. In illustration of this circumstance, I will perform two or three simple experiments. Striking this little bell you will recognise, and you will bear in mind its peculiar note. This is its natural musical sound—the sound evolved by striking it in atmospheric air. I now immerse the same bell in a suspended glass jar containing hydrogen, a gas which is much lighter than the atmosphere, as you are aware. Remark how different is the musical pitch of the note now evolved.



Varying the experiment, I will now cause a tuning fork in the key of C to vibrate over a small glass jar, which, when made to resound, emits the same note, and is therefore in union with the tuning fork. The glass jar vibrates, as you will perceive, to the same note C; but now if I fill this jar with hydrogen, and inverting it to prevent all escape of the gas, cause the tuning fork to vibrate opposite its mouth once more, the unison is destroyed, and the jar no longer sounds responsive to the note C.

Thus you will, I trust, have been impressed with some of the leading points or qualities of the substance nitrogen—its beautiful adaptation to the various necessities of the terrestrial universe. You will be able to contrast in your minds its qualities with those of the elements which have formed the subject of my previous lectures—you will see that its most striking peculiarities consist in the formation of so many varied results of energetic power out of an element so apparently impassive and devoid of energy—in the indirect mode by which its combinations are effected—in their varied, often opposed, chemical qualities when formed—in the vast accession of power which they gain by combination—in the prevalence of nitrogen throughout all the higher organised forms—and in the indifference it displays to the current of passing electricity.

INTRODUCTION TO LECTURE V.

◆

SULPHUR—SYNONYMES, HISTORY, NATURAL HISTORY, PREPARATION, AND QUALITIES.

Synonymes.—Brimstone, Sulphur.

History.—Sulphur has been known from periods of great antiquity, by all nations of whom we possess records, having been employed not only in the arts, but as a medicinal agent. Pliny (lib. xxxv. chap. 15) mentions its use in medicine; also that its fumes (sulphurous acid) were employed in the bleaching of wool.

Natural History.—Sulphur is very extensively distributed in both kingdoms of nature,—most largely as a mineral product, but widely and in small quantities as a constituent of animals and vegetables. Its commercial supply is furnished from volcanic countries, where it occurs crystallised. Occasionally iron pyrites (sulphuret of iron) are employed as a source of sulphur, and sulphur derivatives—namely, sulphurous acid, and indirectly sulphuric acid; but in pyrites, sulphur is usually contaminated with arsenic. Native sulphur is brought for the most part from Sicily, where it occurs in beds of a blue clay formation. On the spot it is subjected to a rough purification by fusing, and being cast into oblong masses or blocks, it is then brought into commerce. Roll sulphur, which is another usual commercial form, is generally the produce of roasting copper or iron pyrites, and collecting the evolved fumes of sulphur in a long chamber of brick-work, and fusing the latter into sticks. *Tablund sulphur*, or flowers of sulphur, is the third commercial state which the element is made to assume, amd is produced by distilling sulphur and condensing the vapour. The appellation *sulphur vivum* designates native sulphur as first dug from its beds.

In the organic kingdom sulphur is found extensively, perhaps universally, diffused throughout animals, and entering in little minute proportions into the greater number of vegetables. Its detection in this minute veiled condition is rendered easy by means of the solution of oxide of lead in potash, as described in the substance of the ensuing lecture.

PROPERTIES.—Sulphur, being one of the substances which can assume not only two series of crystalline forms, each referable to a different system (*dimorphism*), but also two well-marked phases of amorphous condition (*allotropism*), must be described in reference to these characteristics.

If the crystallisation of sulphur have been effected at a temperature below 232° F., it belongs to the right square prismatic system of Weiss and Mohs; if at 232° F., the crystalline form assumed is the oblique prismatic system.

The allotropic amorphous variations of sulphur are commented on, and explained in the ensuing lecture.

The specific gravity of sulphur is from 1·970 to 2·080. It becomes negatively electrified by heat and by friction, and is a non-conductor of electricity. Insoluble in water, soluble in ten times its weight oi boiling oil of turpentine at 316°, forming a solution which remains clear at 800 (Ure), slightly soluble in alcohol, but more soluble in ether. The density of its vapour is about 6·6 (*Dumas, Mitscherlich Ann. de Chem. et Phys.*, l. 170, and lv. 5); hence 100 cubic inches of its vapour at mean temperature and pressure would weigh 206 grains.

PHOSPHORUS—ITS ETYMOLOGY, HISTORY, PREPARATION, AND QUALITIES.

Etymology.—*φως*, light; *φερειν*, to bear; on account of its luminosity in the dark.

History.—Phosphorus is one oi the numerous chemical substances discovered by the alchemists during their vain endeavours to turn the baser metals into gold. Brandt, a merchant of Hamburgh, is the person to whom the credit of this discovery belongs, in 1669. Almost immediately after this period, Kunkel, without any communication with Brandt, rediscovered the process. Meanwhile, Kraft of Dresden had purchased the secret of phosphorus manufacture from Kunkel, and turned its sale to good commercial advantage. In 1680 an account of it appeared in the London Philosophical Transactions, and large quantities of it being now prepared in England by Godfrey Haukwitz, assistant to the celebrated Boyle, the term *English phosphorus* became applied to it.

PREPARATION.—The present source of phosphorus, which is manufactured on a large scale for the purpose of forming lucifer matches and other uses, is the superphosphate of lime, obtained by treating calcined bones with sulphuric acid. Formerly, however, other animal substances were used; but whatever the substance used, the theory of the production of phosphorus depends in all cases on the circumstance that phosphoric acid, or superphosphate of lime, gives up its phosphorus on being heated in contact with powdered charcoal.

The details of phosphorus manufacture as now conducted are as follows:—Pour twenty quarts of water upon as many pounds of calcined bones, and eight pounds of sulphuric acid. Stir the materials well together, and simmer them for the space of about six hours. Next put the whole into a conical bag of linen to separate the clear liquor, and wash the residuum until the water ceases to taste acid. Evaporate the strained liquor, and when reduced to almost half its bulk let it cool. A white sediment will form, which must be allowed to subside; the clear solution must be decanted and boiled to dryness in a glass vessel. A white mass will remain, which may be fused in a platinum crucible, and poured out into a clean copper dish. A transparent substance is thus obtained, consisting of phosphoric acid, with phosphate and a little sulphate of lime, commonly known under the name of *glass of phosphorus*. It yields phosphorus when distilled at a bright-red heat with charcoal. (Brande.)

"Wöhler recommends, instead of the preceding, to calcine ivory-black (which is a mixture of phosphate of lime and charcoal) with fine quartzy sand and a little ordinary charcoal in cylinders of fire-clay at a very high temperature. Each cylinder has a bent copper tube adapted to it, one branch of which descends into a vessel containing water. The efficiency of this process depends upon the silica acting as an acid and combining with the lime of the phosphate at a high temperature, while the liberated phosphoric acid is decomposed by the carbon." (Graham.)

PROPERTIES. — Phosphorus, being one of those substances which are subject to allotropism, assumes two distinct conditions, necessary to be treated of separately. In its ordinary state phosphorus is a tasteless, colourless, or light-buff coloured substance, of wax-like consistency, semi-transparent, and at ordinary temperatures flexible. Its specific gravity is 1·770. It is insoluble in water, but soluble in ether and in oil. At 105°, air being excluded, it melts; and at 550° it boils, yielding a vapour the density of which, according to Dumas, is 4·355. At all temperatures above 32°, phosphorus, when exposed to atmospheric air, is luminous, and a temperature of about 60° F. causes it to burst into flame. This extreme combustibility of phosphorus renders it necessary to keep the substance under water; from which it should be taken, for the purpose of experiment, with great caution, friction being carefully avoided; and whenever desirable to cut it into fragments, this operation should take place under water. Although phosphorus in its colourless or buff-coloured condition is not crystalline, yet this absence of crystalline form is only a collateral result, dependent on the ordinary method of preparation. If phosphorus be fused with about half its weight of sulphur, and suffered to cool gradually, a part of the phosphorus separates in rhombic dodecahedral crystals. (*Mitscherlich Ann. de Chem. et Phys.* vol. xxiv. p. 270.) A hot and saturated solution of phosphorus in naphtha also yields crystals of phosphorus on cooling.

Such are the leading properties of phosphorus in its ordinary or crystallisable state; but lately a new condition of phosphorus has been made known by Professor Schrötter, of Vienna, as constituting an amorphous allotropic state of the element. When common phosphorus is burned, especially in a limited supply of atmospheric air, there results around the focus of combustion a red ring of a substance formerly believed to be *oxide of phosphorus*. Professor Schrötter, however, succeeded in demonstrating that the material in question was generated under circumstances involving the exclusion of atmospheric air, and every other source of oxygenous supply. He proved, moreover, that prolonged heat, within certain limits, was the main condition necessary for the development of this red substance — oxygen being absent — and that a still higher degree of heat re-converted the red substance back into yellow phosphorus. Hence he deduced, both analytically and synthetically, that the red substance in question is merely an allotropic state of ordinary phosphorus.

Identical, however, as is the chemical composition of the two, their properties are widely different .Thus, common phosphorus inflames at a temperature slightly above 60°, whereas allotropic phosphorus only inflames at temperatures above 600, or, more properly speaking, does not inflame even then, seeing that the temperature in question effects its reconversion into ordinary phosphorus. Ordinary phosphorus is soluble in oils, naphtha, ether, bisulphuret of carbon, &c.; allotropic phosphorus is soluble in neither; hence the ordinary plan of employing bisulphuret of carbon as a means of washing out ordinary phosphorus from mixtures of the two.

Nor is the discovery of allotropic phosphorus a mere matter of theoretical interest. Already it has been applied to the manufacture of lucifer matches with considerable success, and a promise of ameliorating one of the most terrible diseases incidental to any manufacture. In addition to the continual danger of burning, to which the workmen engaged in the manufacture of lucifer matches from ordinary phosphorus are exposed, there is another danger still more terrible, because more insidious and more difficult to be guarded against. Exposure to the fumes of phosphorus gives rise to the most frightful disorganisation of the jaw bones, causing excruciating suffering, and usually terminating in death. The slightest spot of caries in the teeth of a workman suffices to become a focus of contamination for the phosphorous vapour; and even those with no such natural disorganisation occasionally suffer. Now, allotropic phosphorus gives off no fumes, neither is it combustible under the usual circumstances attendant upon the manufacture of lucifer matches; hence the advantages presented by this substance are obvious. Unfortunately, however, certain difficulties have hitherto attended its manufacture on the large scale, and limited the employment of this agent—so curious in its chemical nature, so valuable in removing the danger attendant on one of the most noxious operations in the whole list of chemical manufactures.

LECTURE V.

SULPHUR AND PHOSPHORUS.

MATERIALS AND APPARATUS REQUIRED FOR ILLUSTRATING THE LECTURE.

Specimens of native and artificial sulphur and sulphurets.
Specimens of sulphates.
Burnt bones,—phosphates, native and others.
Phosphorus in cylinders.
Long glass tube for burning phosphorus in a current of air.
Iodide of mercury—precipitated—illustrative of allotropism.
Iodide of mercury on paper heated, and cooled again, illustrative of allotropism.
Sulphur—ordinary and allotropic.
Schrötter's allotropic or amorphous phosphorus.
Sulphuret of carbon.
Diamond, charcoal, and plumbago.
Sulphuric acid, (A) anhydrous, (B) hydrated.
Sulphurous acid gas.
Sugar and saw-dust,
Cotton—formation of gun-cotton.
Liquid sulphurous acid.
Liquid chlorine.
Sulphur and copper turnings.
Sulphuretted hydrogen.
Phosphoretted hydrogen.
Sulphur in powder burnt over gas flame.
Imperfect combustion of sulphur in limited amount of atmospheric air.
Albumen—water and potash.
Solution of oxide of lead in potash.
Silver spoon and boiled egg.
Prove that sulphur exists in bread and in flannel.

Preparatory to commencing the subject of his lecture, Professor Faraday directed the attention of his audience to some magnificent specimens of sulphur-yielding materials, belonging to S. Highly, Esq., jun., and placed for examination in the lobby of the Institution.

From an examination of these minerals—remarked Mr. Faraday—you will readily understand how widely diffused is sulphur in the mineral creation. I bring this great manifestation of sulphur before you first, in order that you may observe its most striking, most prominent qualities: however, the chief point of my present lecture, so far as it relates to sulphur, has reference to the hidden, masked, recondite existence of this element in the animal and vegetable kingdom,—long overlooked; but which, since it has been pointed out to us by modern chemists, has become so interesting and so important.

Presently I shall have to advert to these minute organic sulphur combinations,—but, as a preliminary, it will be necessary for me to show you a few of the more prominent manifestations of the substance,—to which end I must select my examples from the mineral kingdom. Sulphur exists very largely combined with numerous metals, constituting by direct combinations sulphurets, or sulphides—by indirect combination, sulphates—some beautiful specimens of which you here observe. It also occurs in volcanic countries—native, or pure. Its leading physical characteristics I need scarcely mention, seeing that they are so very familiar; for instance, it would be unnecessary for me to indicate that, under ordinary circumstances, its colour is yellow—that it is brittle when cold—that it is capable of fusion or volatilisation. There are, however, some highly important and interesting considerations in reference to certain abstruse physical qualities of sulphur, which, not being matters of universal cognisance, require some notice on my part. I must preface my remarks on this subject by stating that sulphur is—according to the definition of chemical nomenclature,—a simple body; that is to say, it has never yet been resolved into further elements. This distinction between simple and compound bodies is, in all cases, regarded by chemists as most important. Deeply interesting is the train of contemplation suggested by this assumed simple nature of sulphur in connection with the subject of *allotropism*,—a subject which has frequently, during the past year, been brought under your notice by various lecturers in this theatre, and last of all by Mr. Brodie,—who, in his able discourse, furnished you with numerous examples of its strange manifestations. These previous developments of the subject of allotropism, however, by others, will not absolve me from the duty of bringing it before your notice again,—seeing that it has an intimate relation with the subject of this morning's lecture. The term allotropism is derived from two Greek words, corresponding, as nearly as they bear literal translation into English, with the expression, *another state;* and is employed for the purpose of expressing the existence of certain bodies in conditions of manifestation different from those which they usually present, although their chemical composition remains the same.

Now, sulphur, I repeat is a simple body; and this circumstance greatly increases our astonishment at its allotropicity—or power of existence in two states,—for sulphur is in the category of allotropic bodies. So long as we are dealing with compounds, the condition of allotropism is not so difficult of rational explanation. We can readily assume, in the latter case, that the elements of which it is composed may be grouped together in more than one system;—although the number of the elements—no less than their nature—should remain the same. This is not difficult to understand; nor is the assumption of varied grouping irrational;—although it may possibly be incorrect, like any other probable hypothesis which admits of no certain line of demonstration; but immediately we come to deal with substances reputed simple, and find them assuming a second condition, our difficulties increase; our grouping hypothesis is no longer applicable; we are left completely in obscurity.

There is more than one indication of the power which sulphur has to present itself under two manifestations. It is susceptible of crystallisation; and crystals of it may be obtained, not merely in two external forms, but these belonging to two different, inconvertible, and incompatible systems. But the most ready and striking means of illustrating the power possessed by sulphur of manifesting itself under two conditions, is furnished by certain phenomena of its melting and subsequent cooling.

Taking a little common yellow sulphur, I melt it in a Florence oil flask, by means of a spirit lamp. Carefully applying the heat it fuses, and the liquid of fusion is then pellucid and transparent. If I pour a portion of this into some cold water, it condenses into the state which it had before melting—that is to say, of common, yellow, brittle sulphur. I now apply a stronger amount of heat, and the transparent, colourless liquid matter suddenly thickens and becomes black; so that the Florence flask may now be inverted without any of the sulphur coming out. If, however, the heat be still increased, the black, tenacious sulphur once more becomes liquid, and gives off a vapour. Now, the vapour of sulphur from this black compound, and its effects, I shall have to bring under your notice by and by. It appears to be endowed with properties different from those possessed by common yellow sulphur—more powerful, more exalted, more energetic; its tendency to react chemically being increased—just as is the chemical tendency of oxygen when it assumes the peculiar state of ozone.

If sulphur in this black liquid state be suddenly poured into cold water, it assumes and retains a very peculiar condition. No longer yellow and brittle, like ordinary sulphur—like the result of pouring into water the first result of fusion—we, however, now produce a substance like strips of india-rubber or gutta percha in its external characteristics, which may be, and is, applied whilst in this condition to take impressions of seals, and which may continue in this second state for days, or even longer.

Before treating of the existence of sulphur as a constituent of organised bodies, I must yet bring before your notice one or two experiments illustrative of its most prominent qualities and compounds. The first experiment is one intended to illustrate the tendency possessed by sulphur to combine with oxygen, and consists in immersing a small lamp of ignited sulphur in a jar of oxygen gas. Vivid combustion, you will observe, takes place, and there results an acid gas of very pungent odour. The latter quality is sufficiently manifest, and the former is made evident by plunging into the jar containing it a slip of litmus paper, which immediately turns red. Now, it is a curious fact in connection with the oxygen compounds of sulphur, of which there are four, that the one containing the maximum amount of oxygen—namely, sulphuric acid—is not generated when sulphur is found in oxygen gas, but requires an indirect process for its formation.

The gaseous result of combustion in this our present experiment is sulphurous acid, the second substance marked in the appended list:—

COMPOUNDS OF SULPHUR WITH OXYGEN.

O	S		
8	16 S 16	48	Hyposulphurous acid.
8 8	S 16	32	Sulphurous acid.

COMPOUNDS OF SULPHUR WITH OXYGEN—*continued.*

$$\begin{array}{ll} \mathrm{O} & \mathrm{S} \end{array}$$

$$\left.\begin{array}{ll} 8 & 16 \\ 8 & \\ 8 & \\ 8 & \\ 8 & \mathrm{S} \\ & 16 \end{array}\right\} \quad \ldots\ldots \quad 72 \qquad \text{Hyposulphuric acid.}$$

$$\left.\begin{array}{ll} & \mathrm{S} \\ 8 & 16 \\ 8 & \\ 8 & \end{array}\right\} \quad \ldots\ldots \quad 40 \qquad \text{Sulphuric acid.}$$

$$\left.\begin{array}{lll} & \mathrm{S} & \\ 8 & 16 & \\ 8 & + & \begin{array}{cc} \mathrm{H} & \mathrm{O} \\ 1 & 8 \end{array} \\ 8 & & \end{array}\right\} \quad = \quad 49 \qquad \text{Hydrated Sulphuric acid.}$$

It is the well-known pungent gas evolved when a sulphur match is burned, and is employed in many purposes of arts and manufacture, especially for the purpose of bleaching or removing colour. But the chief interest of this gas is in connection with its employment in the manufacture of sulphuric acid, or oil of vitriol as it is termed, when brought into commerce in union with water as a hydrate.

SULPHUROUS ACID.

	Grains.
100 C. I.	67·77
To air	2·2464
Hydrogen	32·

[The sulphuric acid of English commerce is a compound of one equivalent real or anhydrous sulphuric acid, and one of water; in other words, it is a protohydrate of sulphuric acid. It is formed by bringing sulphurous acid and aqueous vapour in contact with the red fumes generated by the admixture of binoxide of nitrogen with atmospheric air.*

The process of sulphuric acid manufacture varies in certain respects of detail, but its outline is as follows:—A mixture of sulphur and nitre is burned in such a manner that the results of combustion (sulphurous acid, and binoxide of nitrogen) may be conveyed into a leaden chamber, the floor of which is covered with water. Into the same chamber also enters a steam-jet. After the operation of combustion has been a certain time prolonged, and the water in the chamber has taken up as much sulphuric acid as it will absorb, it is drained off, and a portion of the water evaporated in leaden vessels. The total amount of evaporation necessary, however, can only be effected by means of retorts of glass or platinum, the latter being at this time almost universally employed. The final result is oil of vitriol of

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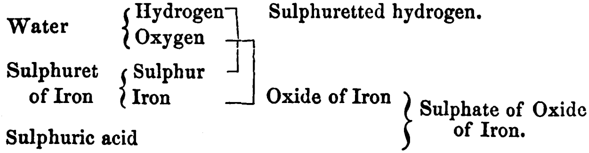
* These red fumes, as was shown in the lecture on Nitrogen, are a mixture in variable proportions of hyponitrous, nitrous, and nitric acids. Sulphurous acid, being a powerfully deoxidising agent, removes oxygen from these, and becoming sulphuric acid falls upon a surface of water provided on purpose, and is dissolved. Occasionally a white crystalline body results in the course of this operation—a compound of nitrous acid, sulphurous acid, and a definite quantity of water—which compound, on falling into a reservoir of water below, becomes decomposed into sulphuric acid, which remains behind, and binoxide of nitrogen, which ascends. This white crystalline compound is, however, by no means an universal concomitant of the production of oil of vitriol, only occurring when the quantity of aqueous vapours employed in the operation has been too small.

English commerce. In some parts of Germany another process of manufacture is followed. Protosulphate of iron being distilled in large retorts, oxide of iron remains, and sulphuric acid, combined with water in the ratio of two equivalents of the former to one equivalent of the latter, comes over. Of this composition is the *Nordhausen* sulphuric acid; and it may be known from ordinary English oil of vitriol by its property of fuming in the air. These fumes are pure, dry, or anhydrous sulphuric acid, which may be obtained and collected by submitting the Nordhausen acid to careful distillation. It is not a little curious that pure sulphuric acid is a remarkably volatile body, whereas the combination of one of acid to one of water (common oil of vitriol), is so comparatively fixed, that any additional increment of water may be readily distilled away from it, as indeed is done in the ordinary commercial method of preparing oil of vitriol.]

When carefully formed and free from water, sulphuric acid has the appearance of a snow-white fuming mass, and is only capable of preservation in this state by carefully excluding the access of air and moisture. When dissolved in water, this snow-like sulphuric acid becomes the liquid sulphuric acid, or well-known oil of vitriol of commerce, a substance of powerful and very remarkable qualities. So powerful is oil of vitriol, so numerous its relations, so extensive its range of combinations, that we must consider it to be the very foundation on which chemical manufactures are built up.

Next in importance and interest after the oxygen compounds of sulphur, comes sulphuretted hydrogen, or hydrosulphuric acid, a compound, as its name indicates, made up of sulphur and hydrogen: nor is it the only compound resulting from a union of the two elements, although the only one which I think necessary to advert to on the present occasion. Sulphuretted hydrogen is naturally formed during the process of organic putrefaction—a circumstance which is demonstrative of a fact I shall have to insist on hereafter, namely, the presence of sulphur as a constituent of animals and vegetables. Sulphuretted hydrogen may also be generated by the direct process of pouring hydrogen over sulphur at an elevated temperature. This is not, however, the most usual process adopted for its preparation, which consists in developing it from a mixture of water, oil of vitriol, and sulphuret of iron, as I shall do here.

DIAGRAMMATIC REPRESENTATION OF THIS DECOMPOSITION.


Water
Hydrogen
Oxygen
Sulphuretted hydrogen.
Sulphuret of Iron
Sulphur
Iron
Oxide of Iron
Sulphate of Oxide of Iron.
Sulphuric acid

SULPHURETTED HYDROGEN.

Sulphur	1 . .	16 . .	94·1
Hydrogen	1 . .	1 . .	5·9
	1	17	100·0

16·6 cubic inches of sulphur vapour = 34·36 grains
100· „ hydrogen = 2·13 „

100· cubic in. of sulphuretted hydrogen = 36·49 „

Sulphuretted hydrogen gas, although exceedingly unpleasant as to odour, is a valuable re-agent to the chemist, who uses it for the purpose of separating metals from their solutions. These applications of the substance are, however, collateral to the purpose of my lecture, which is to indicate the leading peculiarities of sulphur, I have caused a portion of sulphuretted hydrogen to be prepared with a view to subsequent operations.

One more experiment demonstrative of a leading quality of sulphur. Sulphur combines with hydrogen, as we have seen, forming a gas of very remarkable odour and striking chemical characteristics. If I burn this gas with the free accession of atmospheric air, you will observe that no deposition takes place; the result in this case being sulphurous acid, the gas just now produced by burning sulphur in oxygen and water. If, however, I partly close the bottle containing the hydrogen compound of sulphur, just after combustion has set in, then you will observe a powder becomes deposited.

Now, this powder is sulphur; and the experiment demonstrates that, violent though be the combustion of sulphur in oxygen, yet the balance of combining power for oxygen, as between sulphur and hydrogen, is slightly in favour of the latter. Such, then, are a few of the more powerful manifestations of sulphur; and before discussing the curious conditions under which it is found in organic life, I purpose bringing before your notice the leading qualities of the substance phosphorus; which being done, we shall be in a position to discuss the organic relations of both these substances under one head.

The substance phosphorus—of which I here show you a specimen in its common or ordinary condition—although presenting many analogies with sulphur, differs from that substance in many important respects. Sulphur is yellow; phosphorus, when pure, almost colourless: sulphur is very brittle; phosphorus only brittle to an inconsiderable extent: sulphur is combustible, but does not undergo change when exposed to the air; whereas phosphorus, when similarly circumstanced, unites continuously with oxygen, producing intermediately that peculiar exalted or ozonised condition of oxygen, which I have already treated of in a former lecture.

As regards the conditions under which sulphur and phosphorus occur in nature, there is the great difference between the two,—that whereas sulphur is only found in small proportions diffused throughout organic nature, so that whenever we desire to procure it the mineral kingdom is our great magazine,—phosphorus, on the other hand, is but sparingly diffused as a component of minerals: it is to the animal kingdom that we turn for our supplies of phosphorus—to bones and the fluids of the body. These are our magazines of phosphorus, from which, by processes well understood, the substance is extracted in the large quantities now required for lucifer matches and the other manufactures into which phosphorus enters.

The leading characteristic of phosphorus is its extreme combustibility, of which you have already seen an example on the occasion of my treating of oxygen. To illustrate this property in a familiar way, let me just take a minute portion of phosphorus upon the tip of a brimstone match, and rub it — immediately you will observe the match take fire; but the phenomena and the effects of the combustion of phosphorus will be well illustrated by igniting a small portion in an open tube,—which I proceed to do.

Having placed a small fragment of phosphorus in this open tube, I apply heat and ignite it,—when, on impelling a current of air through the tube the phosphorous burns with great rapidity. The combustion having terminated, you will observe the appearance of two different residues—one being a red-coloured substance, and the other white. The latter, or white, substance, is an acid compound of phosphorus with oxygen. Just this sort of result we should, *a priori*, have expected; the former was long imagined to be a combination of phosphorus with oxygen also, but in a lesser ratio than necessary to constitute an acid. Within the last few years, however, M. Schrötter, of Vienna, demonstrated that the red compound in question was merely phosphorus. No combination has taken place to form this red compound, but the phosphorus has assumed a second, or allotropic condition, just as sulphur under the operation of heat does the same.

This allotropic or amorphous phosphorus, prepared in this small quantity by our tube apparatus, is now made on the large scale, and commercially applied to numerous purposes for which common phosphorus was formerly used; and with advantages which will presently appear.

Before we can have a just appreciation of the value of allotropic phosphorus, we must study the characteristics of this substance by comparison with phosphorus in its ordinary condition. Common phosphorus is remarkably combustible; tending to burst into flame on the application of very slight friction or low degree of heat; a quality which renders it well adapted to the purpose of forming lucifer matches. The quality of its colour, and its physical condition as to softness, are also points of comparison. Well, here is a lump of allotropic phosphorus, and you will observe the difference between the two. In the first place, the colour is totally different, that of the allotropic variety being dark;—then the fracture is different, that of allotropic phosphorus being harshly brittle;—but the most striking difference between the two varieties of phosphorus is brought out by the application of friction, or of heat. Common phosphorus we are obliged to keep in water, for the purpose of guarding against spontaneous combustion; allotropic phosphorus, however, may be kept unchanged in atmospheric air; indeed, it may be wrapped up in paper, and carried in the pocket even, with the most perfect impunity: and in this way Professor

Schrötter quite surprised us by his temerity, until we at length gained confidence, and became acquainted with the real qualities of the new substance. Common phosphorus when rubbed takes fire; the allotropic variety, however, may be rubbed with impunity up to a certain point, after which its combustive qualities are brought out. But the extreme use of allotropic phosphorus in the arts will not be comprehended until you are informed of the frightful ravages produced by the vapours of common phosphorus on those who are subjected to their influence, as is the case in manufactories of lucifer matches. Persons thus situated are afflicted with a disease which corrodes, ulcerates, and destroys their bones, causing the most horrible torture, and frequently death. The employment of allotropic phosphorus is attended with no such calamitous results; and being capable of changing into ordinary phosphorus on the application of an adequate amount of heat or friction, it answers perfectly well for lucifer matches, and indeed most of the ordinary applications of phosphorus.

In many other respects these two conditions of phosphorus present differences. Thus, for instance, the power of solution in menstrua is different. Common phosphorus readily dissolves in the sulphuret of carbon, whereas allotropic phosphorus does not. Of this I can show you a ready proof, by pouring two portions of sulphuret of carbon respectively on common and on allotropic phosphorus. You can observe that there is a manifest difference as to the amount of solution; but we shall have a better proof by and by. Pouring a little of each of these solutions on two pieces of paper respectively—the sulphuret of carbon, being exceedingly volatile, evaporates; when, observe—one piece of paper takes fire, owing to the amount of dry phosphorus deposited upon it, whilst the other remains unburnt.

This allotropic change of state is one of the most curious developments of modern chemistry; and now that our attention is directed to the subject, numerous manifestations of this condition are recognisable. Not the least curious fact in connection with this matter is that heat is not an invariable, an indispensable condition to developing the allotropic condition. Thus, for instance, if I add a solution of bichloride of mercury to a solution of iodide of potassium, I may get a yellow or a red compound,—yet the composition of both is identical. Heat effects a similar change. On this paper is painted a red cross—the red iodide of mercury being used as a pigment. If I hold the paper on which is this red cross over a spirit lamp flame, the redness presently changes to yellow. But I must not linger over this interesting subject of allotropism—my time admonishes me to bring before your notice the curious fact of the existence of sulphur and phosphorus in the organic world—phosphorus in large quantities, as I have already indicated; but sulphur in amounts more small—nevertheless, its presence in animals is universal.

PROXIMATE COMPOUNDS OF ORGANISED LIFE.

	Albumen.	Fibrin.	Gluten.	Casein.	Legumin.	Protein.
Carbon	548	546	552	550	541	550
Hydrogen	71	70	72	71	71	71
Oxygen	212	220	218	217	226	219
Nitrogen	149	157	151	158	158	160
Sulphur	7	4	4	4	4	—
Phosphorus	3	3	3	—	—	—
	1,000	1,000	1,000	1,000	1,000	1,000

Most of you are familiar, I doubt not, with the blackening which results on immersing a silver-spoon for some time in a boiled egg; this blackening depends on the presence in the egg of sulphur. In this way sulphur has been demonstrated by modern chemistry to exist in bones, muscle, blood, tendons, milk, wool, and most other animal compounds. If I take this piece of flannel, which has been frequently washed, and plunge it into a mixture of oxide of lead in a solution of potash, and apply heat, the flannel immediately turns black, owing to the sulphur which it contains.

And in this way the presence of sulphur may be proved to be almost universal in the animal kingdom. Formerly it was assumed that substances which existed in such small quantities as sulphur does in animal structures, were casualties. The fallacy of this opinion is, however, now recognised, and England at length is aroused to the necessity of supplying, in the form of manures, the exhausted elements of her soil.

It is not a little strange at this time to reflect on the period which elapsed before the origin of these so-termed casual substances existing in plants and animals was at all understood. Take sulphur and phosphorus for instance, and consider them in relation to animals. Either they enter the tissues of animals by the ingestu, or they are formed there,—and if the former doctrine be received, as it necessarily must, then have we to determine in what manner the substances in question get into plants; these evidently being the basis of animal life. Now it has been proved—especially by the German chemists to whom the world is so much indebted,—that plants obtain these substances from the earth. Hence, the chemical analysis of a plant is the first step towards our knowledge of the proper manure for it. It has been proved that certain plants absorb constituents of one kind, some of another; and hence a soil which has become barren for one sort of crop may be fertile for a second. This consideration leads us to understand the necessity for a rotation of crops, and for supplying to lands by means of manures the materials which they have lost.

It would be difficult at this time to contemplate the injurious results which have flown from the old assumption that vegetables were entirely made up of carbon, hydrogen, and oxygen—animals, of these elements and nitrogen. Notwithstanding other ingredients were continually found, both in animals and vegetables, yet for some reason, which it would be difficult to account for, they were put down as extraneous casualties. The only seeming reason for assuming them to be casualties, is the smallness of the quantity in which they are found,—a very unphilosophical reason in any case, and one which in this instance has been mainly dependent on the imperfection of our tests. See what a beautiful means of demonstrating the presence of sulphur does our oxide of lead and potash test afford,—and how universally does it prove the distribution of sulphur in the organic kingdom. If we had tests of equal delicacy for other constituents, we should then perhaps have equally ready evidence of their existence.—Thus if we go through an elaborate analysis of organic beings, we find, instead of the three or four elements formerly acknowledged as their invariable constituents, a long list of others—small in quantity, it is true,—but invariably present; doubtless, not put there by mistake, or as a casualty. Thus, looking at the analysis of wheat-flour, we find instead of three, or at the most four bodies, carbon, hydrogen, oxygen, and nitrogen, no less than nine recognised ultimate elements, and probably others may yet be discovered.

THE CONSTITUENTS OF WHEAT FLOUR.

Ultimate Elements.	Proximate Elements.
Carbon	Gum
Hydrogen	Sugar
Oxygen	Starch
Nitrogen	Lignine
Sulphur	Albumine
Phosphorus	Fibrine
Calcium	Caseine
Magnesium	Glutine
Silicon	Fat (and Ashes)

It is this extensively distributed masked or hidden condition of phosphorus and sulphur in the two organic kingdoms, and the allotropic condition which each of these bodies can assume, to which I especially wished to direct your attention; passing over the more gross and ordinary conditions of these elements with little comment, as being subjects which from their prominence have been extensively discussed and are well known.

I shall now conclude this lecture by manifesting the power of combination enjoyed by sulphur under certain conditions of heat and vaporisation—a power which we are very apt to forget is possessed by this element, simply because we do not find it, in the ordinary range of material circumstances, placed under conditions favourable to its exercise. We are apt, for instance, to regard the element sulphur as possessing combining properties very different in the amount of their vigour from those possessed by chlorine; yet I do not know that we are just in arriving at this conclusion. If certain metals in a very fine state of comminution be dropped into an atmosphere of chlorine the metals take fire and burn, whereas the same metals may be brought into contact with sulphur without any such effect resulting. But chlorine naturally exists in the state of gas—whereas sulphur does not. Accordingly, if I expose copper turnings to the influence of vaporised sulphur, which can be done by means of a very simple apparatus, you will observe a different effect. Into this flask I put some fragments of sulphur, above them some copper turnings,—and now I apply heat. Vaporised sulphur rises, comes into contact with the copper turnings, and causes them to enter into vivid combination, just as we observed in the former experiment with chlorine.

INTRODUCTION TO LECTURE VI.

CARBON—ITS HISTORY, NATURAL HISTORY, VARIETIES, AND PROPERTIES.

History.—Carbon, under most of the numerous forms which it can assume, has been known from time immemorial. Under the different conditions of charcoal, diamond, plumbago or black-lead, and plumbagine, it furnishes an instance of that interesting quality *allotropism;* although this fact was for a long period overlooked, or allowed to pass under the eyes of observers without reflection. Carbon exists in both kingdoms of nature, although it may be considered as especially belonging to the organic world—for the coal deposits, which are the main store of carbon in the inorganic kingdom, are well known to be of vegetable origin. The purest form of carbon, as ordinarily procured, is charcoal; which is developed by exposing animal or vegetable substances to heat, atmospheric air being excluded. The forms of apparatus for conducting this operation are various—the most efficient consisting of retorts or distillatory cylinders, by means of which, at the present time, all the charcoal employed in the manufacture of gunpowder is produced.

The means commonly had recourse to for the preparation of charcoal are illustrative of a leading chemical quality of this body—its complete fixity even at the highest temperature, provided the accession of air, or oxygen, be prevented.

Even when prepared from wood of different species the resulting charcoal differs as to its density, its power of electrical conduction, and certain other characters; but on examining other forms of black carbon, such as anthracite coal, coke, Kilkenny coal, plumbago, and plumbagine, other points of characteristic difference will be recognised. Common bituminous or caking coal is not carbon, but an association of many complex unions of carbon and hydrogen, from which heat expels the volatile parts, leaving coke behind, which is a mixture of carbon with small quantities of metallic oxides.

Amongst the most interesting forms of black carbon is plumbago, or black-lead—formerly considered to be a carburet of iron. The best specimens of plumbago, however, are altogether free from iron: hence this metal can only be regarded as an accidental impurity. Lead is never present in plumbago: hence the appellation *black-lead* is altogether a misnomer, and appears to have been given merely on account of the black mark, somewhat similar to that of lead but deeper, which plumbago leaves on white surfaces.

The employment of plumbago in the manufacture of pencils is too well known to require comment. For this purpose the best quality of plumbago was the produce of Borrowdale, in Cumberland; but the vein is now quite exhausted, and other sources of plumbago have had to be sought. Most of the ordinary pencils now used are manufactured from a factitious paste, made of powdered plumbago, antimony, and sulphur fused together, cast into blocks, and these blocks sawn into bars of the required length and size. The great disadvantage of these pencils is their harsh grittiness, and the difficulty with which their marks are effaced by Indiarubber. A better sort of pencil—the best of all for certain effects, is made by subjecting the powder of plumbago to extreme hydrostatic pressure simultaneously with the abstraction of all remaining traces of air by means of the air-pump. The result of this treatment is a block, which, when cut by the usual method furnishes the bars that, properly mounted, constitute Brockedon's pencils;—preferred by Harding over all others, and which are undoubtedly the best for the purposes to which they are applied by that gentleman.

PLUMBAGINE is a term which has been applied to a material very much like plumbago in appearance, and which is formed, under certain circumstances, in gas-retorts. Ivory and bone black are varieties of charcoal which result from the concentration of ivory and bones in retorts. They are employed for a variety of purposes. Ivory black forms a constituent of the finer kinds of printing-ink—especially that used for copper and steel plate engraving. The preparation of bone black now constitutes an enormous manufacture, its chief use being the decoloration of raw sugar in the operation of refining. For this purpose the bone black is prepared in the state of grain, packed into large cylinders, and the coloured sugar solution allowed to percolate through. This operation illustrates a function of charcoal, especially the variety termed animal charcoal, to bleach or decolourise. Still, in the case of bone black, it would be a mistake to assume that charcoal possesses the sole decolourising agency manifested by that substance, of which almost 90 per cent. is not charcoal, but carbonate and phosphate of lime, mixed with iron salts and some other bodies; yet if this 90 per cent. of matter not charcoal be removed by digestion with an acid, then the remainder, which is pure charcoal, does not decolourise, weight for weight, equal to the original and impure mixture.

THE DIAMOND.—By far the most extraordinary and beautiful, as well as the most valuable, form of carbon is the diamond, a gem which has been known and valued on account of its resplendent beauty from the earliest ages. Since the year 1720, when diamonds were first discovered in Brazil, that country has been their chief source; anterior to which period they were exclusively brought from India and Borneo.

The composition of this gem is undoubtedly carbon, seeing that the sole result of its combustion in oxygen is carbonic acid gas: but the origin of the diamond is a subject of much curious speculation. Seeing that its structure is crystalline, the diamond should have been at some early period in a liquid or semi-liquid condition; a state which presupposes fusion by fire, or solution in some menstruum. Opposed to the first hypothesis is the circumstances that within the structure of many diamonds are seen remains of organic beings—appearances scarcely consistent with the assumption that the diamond was once in a state of igneous liquidity. Sir David Brewster inclines to the opinion that the diamond is a drop of fossilised gum.

Although the diamond has been celebrated for its beauty in all countries and all ages of which we have any notice, yet the extreme beauty which this gem is capable of assuming can only be developed by an ingenious and tedious process of cutting unknown even to this day in its full perfection by Eastern nations, and of somewhat modern introduction to Europe, viz., in the year 1456 by Louis Berghen, of Bruges, who accidentally discovered, that by rubbing two diamonds together a new face was produced. In other words the diamond is so hard that it can only be abraded by portions of its own substance: hence, diamond powder is universally employed for that purpose; such stones as, on account of their inferior colour or their flaws, are valueless as gems, being broken down into powder for the purpose of cutting others. At present, and for a long time past, the head-quarters of the diamond cutting operation are at Amsterdam, where the operation is conducted by Jews exclusively. Their machinery is of the roughest kind, and horses are still employed as the propulsive force. The exact method of procedure is this:—the diamond to be cut is attached by means of a very fusible species of solder to the face of a sort of hammer, the extremity of the handle of which being supplied with a hinge by which it is restrained as regards lateral motion, but allowed free liberty to move vertically. The face of the hammer being now turned towards the flat surface of a horizontal wheel, primed with diamond-dust and oil, and the wheel being put in motion, that portion of the diamond which comes in contact with the wheel is ground away. This gem, however, being subjected to definite crystalline forces of aggregation, cannot be ground into any form at pleasure—but only certain varieties of forms correlative with the exercise of crystalline force. Subordinate modifications of form being omitted, cut diamonds may be described as falling under the category of *brilliants* and *roses*. The former, which are the most beautiful and valuable, may be recognised by their flat summits, whereas the summits of rose-diamonds are peaked.

The weight of diamonds is estimated in carats—150 of which are equal to one ounce troy or 480 grains. These carats are subdivided into halves, quarters, or carat grains, eighth, sixteenth, and thirty-second parts.

The rule for the estimation of the value of diamonds is peculiar, and supposing the gems under comparison to be equal in quality, may be expressed as being in the ratio of the squares of their respective weights. Thus, supposing three diamonds to exist, weighing respectively one, two, and three carats, their respective values would be as *one*, *four*, and *nine*. The value of a brilliant diamond is considered equal to that of an uncut diamond of double the weight. This rule, however, can only be considered as applying to gems of moderate dimensions: very large diamonds, if estimated according to this mode of calculation, would become expensive beyond the means of the richest to command.

The history of the large diamonds known to exist in different states possesses great interest, as showing the vicissitudes through which some of these beautiful gems have passed before arriving at their final resting-place. It is a subject, however, which scarcely comes within the scope of this volume. The celebrated Koh-i-noor, which probably may now be regarded as the most beautiful diamond in the world, is believed by Professor Tennant and some other competent authorities to be only one portion out of three of a diamond of extraordinary size*; the second portion he agrees with Dr. Becke in considering a diamond slab, belonging to Persia, described at the meeting of the British Association at Ipswich, in 1851; the third he considers to be the great Russian diamond.

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* Having weighed, according to Tavernier, 787 carats; and being worth nearly two and a half millions of pounds sterling. The Persian diamond weighs 130 carats; the Russian diamond, 196. The Koh-i-noor as exhibited in 1851 weighed $186\frac{1}{16}$ carats. Since then it has been recut, and now it only weighs $102\frac{3}{4}\ \frac{1}{16}$ carats. For this information I am indebted to Professor Tennant.

RESPIRATION.

THIS important function is, so far as we know, absolutely necessary to the existence of all living beings, whether animal or vegetable, but it is in the economy of the animal world that the function is most distinctly marked.

Although every animal accomplishes the act of respiration, the organs by which the act is performed differ essentially in the various divisions, and even in the various sub-divisions of the animal world.

The lowest type of animal organisation is usually considered to be that of the polypus, and respiration in these animals is accomplished exclusively by the skin. They are totally devoid of lungs or gills, or any other localised organisation for performing the respiratory function,—the skin constituting a respiratory apparatus sufficiently powerful for their wants.

To those who may not have devoted some consideration to the subjects of physiology and comparative anatomy, it may seem extraordinary that respiration should be accomplished by the skin; yet the functions which we recognise under an extreme manifestation in the polyp, occur, although less strongly marked, in probably every animated being. In man, although provided with two voluminous lungs, yet the skin is to some extent a respiratory organ. This fact is satisfactorily, though painfully, demonstrated by the occurrence of extensive burns, which produce, as one of their most common and most fatal results, extensive disease of the respiratory organs. The rationale of this occurrence is very easily found. Normally, whilst in a condition of health, the skin tranquilly aids the lungs in one of their chief labours, the expulsion of carbonic acid from the body; but the portion of skin which has been scorched by an extensive burn, no longer being able to perform that function, the lungs are obliged to assume an extra duty, and suffer as a consequence of their exertion. The evidence of this connection existing between the lungs and the skin of man renders it less surprising that Nature should have thought fit to cause certain animals to depend entirely on the skin for performing the function of respiration. Ascending in the scale of animated creation, we find that the function of respiration becomes more or less localised, although the indication of a similarity between the functions of the lungs and the skin may be recognised even so high in the scale of life as man himself.

Localised organs of respiration assume the aspect of either lungs or gills, or tracheæ. Lungs are for the most part confined to animals belonging to the great division *Vertebrata* of Cuvier, including all animals which are possessed of vertebræ, or a back bone. Nevertheless, lungs are not exclusively confined to the division of animals; for example, many of the *arachnida*, or spider tribe, are supplied with lungs, as in like manner are two genera of snails.

Insects, without exception,* breathe by the organs called *tracheæ*, or wind pipes—tubes which penetrate in various directions their bodies, and terminate externally in open orifices called *stomata*. If these stomata be secluded by any thick liquid—such as a little oil—an insect speedily dies,—a result which probably has been often seen in the case of a troublesome wasp. Ascending through the scale of animated creation until we arrive at the highest division of Cuvier, namely, Vertebrata, including as it does the classes of *mammalia*, *aves*, *pisces*, and *reptilia*, we find each member of these tribes to be endowed with some localised organ of respiration, either in the form of gills or lungs. Mammals and birds are all supplied with lungs, and reptiles for the most part. The batrachian or frog tribe of reptiles, however, breathe by gills at one period of their development; and a few creatures—standing on the confines of the fish and the reptile, so that naturalists are puzzled under which head to classify them—breathe by both lungs and gills. Of this kind are the *Lepedosiren*, the *Siren*

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* Spiders must not be confounded with insects, from which they differ in having lungs, in possessing eyes very much like our own—also, a different cerebral organisation, and higher intelligence.

Lacertina, the Menobranchus, the *Axolotl,* and lastly the *Proteus Anguinus.** All of these creatures are

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* The Proteus Anguinus is an European animal, connected with whose existence there is a great deal of mystery. A graphic description of one of the two localities in which the animals are found, has been given by P. E. Turnbull, Esq., in his volume on Austria. Murray, 1840. It is as follows:—

"Our three guides stationed themselves at various points, and brandishing their large torches aloft, showed well this solemn cavern, with its huge pillars and dark dull waters—rendered the more interesting to the fanciful mind as being the habitation of that mysterious animal the Proteus Anguinus, which, except in one other spot (also in Carniola, near Sittich), has been found nowhere else.

"This creature appears to be bred in some much lower subterranean lake, and to be borne up into these comparatively upper regions when the waters swell. We are told that during a considerable part of the year there is no water whatever in the cave of the Magdalena. In the winter and spring it rises through crevices from below; and even then is the Proteus only occasionally discovered. It is found in the Poik (if the water to the right of the entrance be the Poik) in this cavern, but never in that of St. Catherine, nor in any other part of the river: neither is any other fish or living creature said to be found in the Poik after its first entrance below the earth. It is found also in the water which I have mentioned to the left of the entrance, supplied probably to them both from the same resorvoir or river beneath. To this water on the left we partially descended, but the drippings had rendered the soil muddy and unsafe. One of the guides, however, stationed at the bottom with his torch and hand-net, endeavoured to catch two or three of the Protei; but on his attempting to take them, they escaped under the rock.

"On our return to the inn at Adelsberg, I saw some of these creatures alive in a decanter of water, where, by changing the water every day, and without any other food, they had lived (as their owner told us) more than a twelvemonth. They were about supplied with both lungs and gills, both so equally developed that naturalists vary in their opinions as to

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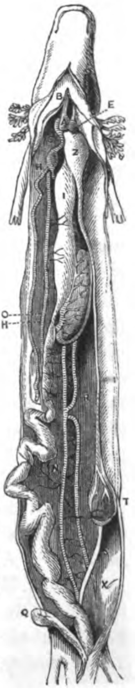
seven inches long, and perhaps half an inch, or somewhat less, in diameter; the form of body somewhat like an eel, but with four legs regularly jointed like quadrupeds'—the two fore-feet having three toes, the two hinder two only; the legs about an inch long, and the hinder ones at a great distance from the fore; colour, a greyish white; head very large, with a large broad mouth; two very small eyes, and behind the ears the gills of a fish. They have a double apparatus for breathing, and form a mixture or link of connection between the fish and the quadruped.

"Doomed, apparently, to live in eternal darkness in the abyss of an Illyrian mountain (for their upheaving into the caves must be considered as an exception), it might seem strange that the creature should be provided with eyes. Some imaginative writers have deemed that they had formerly a higher locality, and that amid the various convulsions of the globe, some retirement of the waters may have carried the relic of a nearly-destroyed race to its present asylum. It may be more philosophical to suppose that the small portion of light accompanying air through the crevices of the mountains, although imperceptible to our organs, may suffice to direct the course of these more delicate creatures. It is evident from the length of time that they had lived in the bottle, that the light and air of this upper world are not destructive of their vitality. Those which we saw were moving about with activity over each other, and climbing with a sort of reptile motion along the sides of the glass.

"Whether their propagation has been attempted in other places, I know not. Some were transported to the St. Catherine Cave, and placed



which character, the fish or the reptile, predominates.* Fish breathe exclusively by gills,—a form of respiratory apparatus adapted with admirable wisdom to the end which Nature has in view,—the extraction of oxygen dissolved in water, instead of oxygen in the gaseous form.

The aerial creature requires for the performance of respiration an apparatus which, by its innumerable vesicles, shall afford a large area of open space. The aquatic creature, on the other hand, requires an apparatus of a kind totally different. Instead of vesicular lungs—bloodvessels imbedded in cellular tissue and expanded over the walls of mucous chambers—the fish requires its lungs to consist of the bloodvessels unravelled from all covering, pulled out into the state of fringe, and allowed to float in the water. This modification of the lungs constitutes gills. Turning our attention exclusively to lungs, we shall find a beautiful subject of

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therein, mostly in the river, but partly also in small standing pools. Those in the former may still exist—the water is too deep and dark to allow the fact to be ascertained with certainty; but none have been seen or caught. Those in the pools have disappeared—stolen, it is supposed, by the strangers visiting the locality." The woodcut in the preceding page represents a Proteus dissected.

* Two distinct species of the Lepidosiren have been met with; one the *Lepidosiren paradoxa*, discovered by Dr. Natterer in the river Amazon; the other, *Lepidosiren annectans*, was found by T. C. B. Weir, Esq., and is a native of the African continent, inhabiting the river Gambia. An individual of this last species has been minutely anatomised by Professor Owen.—*Trans. Linn. Society*, for 1840. The Siren Lacertina inhabits the marshes of Carolina.—*See Jones's Animal Kingdom*, p. 538.

contemplation in the manner of their variation to suit the habits and necessities of various beings. In man, and all mammalia, the lungs occupy a large portion of the chest, constituting massive, heavy organs, into which the air is made to rush by the muscular expansion of the cavity in which they act. Such an arrangement of lungs, however, would by no means accord with the conditions to which the feathered tribe is subjected. In four-footed animals the mere increase of a few pounds to their bodies—such an increase as is involved in the provision of capacious lungs—matters not; but an increase of a few pounds' weight to birds—creatures which have to spend much of their lives suspended in an attenuated medium by the pure force of muscular exertion,—to these the increase of a few pounds in weight would prove of the most serious detriment. Yet birds require a very perfect performance of the respiratory functions. They are emphatically hot-blooded animals; and as animal heat is both an indication and a measurer of respiratory activity, it follows that some perfect respiratory apparatus must exist in birds. They are supplied with lungs of a very peculiar kind; not those large, bulky, vesicular appendages which four-footed animals carry about in their chests; but small compact, immoveable, non-expansive organs, held securely by ligaments to the back bone. It follows, therefore, that if the lungs of birds cannot expand, some provision, different to that which exists in four-footed animals, must be adopted.

The provision is very beautiful, and is as follows :—The bones of birds are hollow, and being hollow, are always filled with air; moreover, air cavities exist in various parts of the body, the gaseous element penetrating even into the muscular sheaths. Hence the lungs, not being required as vessels of capacity, but merely as instruments of chemical action, are smaller than they would have otherwise been required to exist. But there still remains to be devised a provision for filling the lungs with air, otherwise than by expansion. The muscular exercise of the animal is made subservient to this end. When at rest, and when respiration is but little required, the bird, by means of a slight muscular motion, causes sufficient air for its present necessities to enter the tiny lungs; but when the same bird is exposed to the violent exercise of flying, and when, consequently, the function of respiration is required to assume its highest grade of intensity, then the increased muscular action of the bird is made subservient to the end. Every flapping of the wings against the ribs throws a set of muscles into activity, which, by their contraction, force a largely increased supply of air into the lungs; and thus the performance of a function is accomplished as a necessary result of attendant circumstances.

Lungs of almost the same external character, though different in their internal conformation, are supplied to reptiles, although not for the same reason. In the serpent and lizard tribe the large, heavy, expansive lungs of mammalia would be evidently incompatible with the conditions of their little, slender, elongated forms; but frogs have the same kind of lungs, and may be frequently seen to inflate them with air by a very simple, yet at the same time very effectual process. A frog may occasionally be seen moving inwards and outwards the sides of his face and the skin of his capacious throat. The animal is performing an act of respiration; not as we perform it, by expanding our chests; but this motion of the face and throat is precisely analogous to the motion of the leather of a pair of bellows—a motion by which the animal *forces* air into the lungs.

The chemical portion of the respiratory function chiefly involves the removal of carbon from the lungs. According to the experiments of Allen and Pepys, who were the earliest to investigate the chemistry of their function, the removal of carbon in the form of carbonic acid was the sole object; and according to them the carbonic acid corresponded exactly in proportional quantity with the amount of oxygen taken in. Later investigations, however, have proved that the explanation is not quite so simple; have proved that a portion of oxygen is absorbed, that nitrogen is sometimes absorbed, at other times given out. Still the most prominent consequence of the respiratory function in animals is evidently the removal of carbon from the blood, in the form of carbonic acid.

And now a very beautiful provision of Nature is rendered manifest to us. Carbonic acid being continually evolved from animals would soon render the atmosphere unfit for respiration, did there not exist some purifying agency or agencies. Doubtless there are many such with which we are not conversant; but one, and a very powerful one, is evident—namely, the purifying agency of living vegetables. It is their function to assimilate the element of carbonic acid which animals reject: it is their object to fix carbon. Hence they absorb carbonic acid by their leaves, fix carbon, and set oxygen free. So admirably is the balance of atmospheric composition maintained that the amount of carbonic acid scarcely varies in any part of the world—constituting one part in a thousand of atmospheric air. Now, the total amount of atmosphere being known with tolerable accuracy, and, consequently, the total amount of atmospheric carbonic acid, a doubt has been mooted by some, whether that amount be sufficient for supplying and keeping up that large amount of carbon which vegetables require. Calculation shows that the amount of atmospheric carbonic acid is sufficient for this end; but pursuing the contemplation further, the question was mooted, whether an atmosphere containing no more carbonic acid than at present could have been reasonably assumed to have furnished that enormous amount of carbon which is stored away in coal-fields. Probably, it was assumed, the atmosphere in that early period of the world, when coal-fields were deposited, contained more carbonic acid than it does at present; but for the greater number of vegetable species, an atmosphere charged with any considerable amount of carbonic acid over and above that supplied to us is fatal. As regards the fern tribe, however, they have been proved by experiment to be capable of living and thriving in an atmosphere containing an amount of carbonic acid fatal to other species. Now, the fact is well known that coal-fields are chiefly made up of the remains of gigantic ferns; and hence we recognise the exercise of a wise foresight in so adapting the organism of these vegetables, that they could live and flourish in an atmosphere of carbonic acid which would be fatal to most other vegetables and the higher orders of animals.*

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* All the animal remains which have been disclosed in older geological formations than coal are of very low organic types, to the organism of which, judging from their existing analogies, carbonic acid would not be injurious.

LECTURE VI.

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CARBON.

NOTES OF MATERIALS AND APPARATUS REQUIRED FOR ILLUSTRATING THE FOLLOWING LECTURE.

Slips of paper dipped in alum or borax.
Specimens of charcoal, diamond, plumbago, coke, &c.
Diamonds turned into coke.
Animal charcoal.
Tincture of litmus.
Materials for illustrating the process of fermentation:—
  Jars of carbonic acid.
  —— of carbonic oxide.
Apparatus for burning the diamond in oxygen gas.
Lime-water.
A burning candle to illustrate the property of flame.
A jar of olefiant gas, and another of chlorine, ready to be mixed.

[This was the final lecture of the course of six, "On the Non-Metallic Simple Elements." The theatre was very fully attended, and his Royal Highness Prince Albert honoured the audience by taking the chair.

The lecturer commenced by directing the attention of his audience to the various pieces of carbon present on the table—the diamond, coke, charcoal (animal and vegetable), plumbago, and diamonds partly converted into the black amorphous form.]

The first point in connection with the natural history of carbon, is the circumstance of its invariable solidity. This quality I shall have to allude to again in connection with some of the most usual functions of carbon: it is one which lies at the foundation of almost every useful application of the substance.

Notwithstanding this fixity of carbon, it is strange to recognise certain chemical effects capable of being produced by this element: thus, for instance, it has the power of absorbing larger bulks of various gases — of removing putrid smells and certain colouring matters.

Yet, (continued Mr. Faraday,) the chemical agency of carbon in an isolated state is but insignificant when compared with the wonderful energies called into play in its various combinations. To me, viewing as I do the qualities of each element in relation to its most obvious functions in the economy of the universe—speculating on what must have happened had these qualities been different to what they are—pondering over the all-wonderful foresight by which the harmonious balance of elemental powers was predetermined and is maintained—this fixity of carbon, in comparison with the volatility of its compounds, is a subject of never-failing interest and admiration. This is a subject which will prominently appear as I go on, and more especially after I shall have taken up the oxy-compounds of carbon. Of these oxy-compounds there are two—the carbonic oxide and the carbonic acid gas.

CARBON WITH HYDROGEN AND OXYGEN.

Carbonic oxide	$C\,O$
Carbonic acid	$C\,O_2$
Carburetted hydrogen	$C\,H$

As regards the first, of which we have a specimen near, it is of frequent occurrence in many common instances of combustion. All who are here probably have seen a charcoal fire, and have recognised a peculiar blue lambent flame which plays upon the ignited coal: this flame is produced by the combustion of carbonic oxide. Another common instance of its occurrence is in an active limekiln; over the ignited lime there plays the same lambent flame. These instances may be sufficient, without experiment, to impress upon your minds the two leading qualities of carbonic oxide gas—its inflammability and the peculiar colour of its flame. But in this jar I have some of the gas in a pure state, and can demonstrate its combustibility and peculiarity of combustion by withdrawing the stopper and applying a light.

Of carbonic oxide little is said in comparison with the general repute of carbonic acid, yet its functions in many operations are highly important: and, as regards its agency on the animal economy, the experiments of Dumas have shown that it is at least a hundred times more poisonous than carbonic acid. This is a fact which was until lately unknown; carbonic acid having been considered as the more poisonous gas. However, without repeating the experiments of

Dumas, they have been propounded on such evidence as I am willing to accept as perfectly conclusive. Now, this extremely poisonous nature of carbonic oxide is a fact of great significance when we regard it in connection with certain proposed plans of illumination which contemplate the employment of this gas. In itself carbonic oxide has but little illuminating power, as you have seen; but illuminating power can be given by causing it to absorb certain particles extraneous to itself, and in the end it may be made a good illuminating source. Should this plan of illumination be carried out, it will be necessary, after the experiments of M. Dumas, to watch attentively the first results; for, although the speculative chemist should be most careful not to impede, by undue expression of vague fears, the progress of any discovery, yet, on the other hand, facts so significant as those indicated by M. Dumas should not be passed by unheeded. Accordingly, I have been made aware that in France, where matters of public health are much more studied than in England—much more taken cognisance of by the Government—competent persons are anxiously watching the first effects of the new illuminative gas, considered under a sanitary point of view, and are authorised to forbid the process on the first manifestation of a result unfavourable to health.

Passing away from carbonic oxide with this short notice, we now arrive at the consideration of carbonic acid. This body, like the preceding, occurs naturally in the form of a gas, although it has been condensed into the fluid and the solid condition. This gas is the highest form of combination of carbon with oxygen, and is the one which naturally results when carbon is burned in atmospheric air or oxygen gas; it is also the gaseous result of fermentation, as can readily be made evident by the following experiment. Into a globular vessel has been put a mixture of one part sugar, four parts water, and a little yeast,—and the whole mixture having been exposed to a temperature between 70° and 80° F., the process of fermentation has set in. The vessel is now filled with carbonic acid gas, as I have no doubt can be manifested.

I should preface the trial, however, by stating the evidence by which the presence of carbonic acid can be demonstrated. In the first place, then, carbonic acid gas is so much heavier than atmospheric air that it can be poured, after the manner of a liquid, from one vessel to another. In the second place it neither burns nor supports combustion—then, if agitated with lime-water, the latter affords a white precipitate: chalk or carbonate of lime—in addition to which qualities it reddens turmeric and has a peculiar smell. Any gas possessing these qualities must be carbonic acid. Let us now observe whether such have been produced.

[At this stage of the lecture Professor Faraday performed the usual experiments demonstrative of the great weight of carbonic acid gas, its negative qualities of neither burning nor supporting combustion, its slight acid reaction on litmus paper, and its quality of precipitating lime-water white.]

It will be unnecessary for me to repeat the experiment, already performed on a previous occasion, of burning charcoal in oxygen gas; that experiment will have been remembered, and indeed it is sufficiently common. Less common, though now well known, is the experiment of burning the diamond in oxygen gas, and demonstrating that the result of combustion is carbonic acid. When the experiment was first performed, the result was considered extraordinary. Of course, we do not regard it as extraordinary now; but the extreme interest of the reaction shall be my apology for repeating the experiment.

[The combustion of the diamond was here effected, the gem being held by a little platinum clamp and ignited to whiteness in the oxyhydrogen flame, then plunged whilst incandescent into a jar of oxygen. Eventually the resulting gas was proved, by means of the lime-water test, to be the carbonic acid.]

Thus the evidence as to the identity of carbon with the diamond is sufficiently made out by this one experiment; nevertheless, if further evidence were required, it could be supplied by the beautiful result which I have in this glass case. Here are some diamonds which have been exposed under peculiar conditions to an intense heat; and with the result of converting them into coke. The gems will be seen to have lost their crystalline aspect—to have opened out, forming a cauliflowerlike excrescence, and to have assumed the aspect of coke. These interesting specimens have been sent me from Paris, and they are most curious as furnishing us with another instance of allotropism,—that mysterious existence of identical matter in two states.

Having seen the fixity of carbon in its pure state, and the volatility of its oxygen combinations, we shall now be in a position to appreciate the nice adaptation of qualities which render it so valuable as a fuel. Had carbon not been fixed, our furnaces and fireplaces would have had no local place of action—no focus wherein their powers might have been concentrated. Had the results of combustion not been volatile, the combustive action would have been continually impeded. There can scarcely be conceived a more beautiful balance of powers designed for the accomplishment of a specific end than this; yet so familiar has the result become to us—so unnoticed by its very perfection—that an effort of chemical reasoning is required to enable us to justly appreciate this point in relation to the chemistry of carbon. The enormous quantity of ponderable, yet invisible, carbon removed in the draught of our larger fireplaces is, on its first announcement, startling; yet nothing admits of more satisfactory proof. Through an average-sized iron blast-furnace there rushes hourly no less a quantity of atmospheric air than six tons, carrying off fifty-six hundredths, or more than half a ton, of carbon in the form of carbonic acid.

Now, carbonic acid is not a supporter of combustion, as we have on many occasions seen; hence, if it had lingered in the furnace instead of being so readily dispersed, the fire could not have been maintained. This condition, as it would have been had the result of combustion been fixed, may be conveniently illustrated by a simple experiment. Taking a mass of potassium or any combustible substance, as we have seen before, I heat it on a piece of platinum-foil; yet the potassium does not take fire. Still more I urge the heat; the potassium fuses, rolls about on the platinum-foil, and becomes rapidly covered with a white crust; but it does not burn. But why does it not burn? Not certainly because of any inherent incombustibility, since, if I throw it into water, so great is its power of combustion, that it immediately bursts into flame.

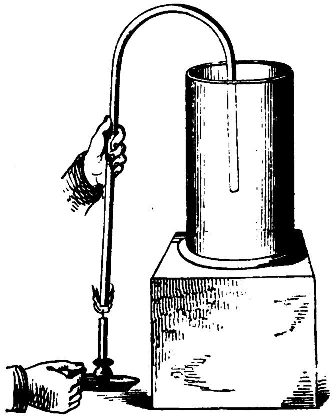
Another point of deep interest in the chemistry of carbon is its strong power of illumination when incandescent. You have already remarked how trifling was the amount of light evolved from phosphorus burning in chlorine gas, or sulphur in the same gas, or sulphur in oxygen; how seemingly powerless it was, although really coexistent with highly developed chemical power. You have remarked, too, the extreme vividness of the light produced by the combustion of phosphorus in oxygen. The light developed during combustion is so far from being in any direct ratio with the accompanying heat, that the very reverse of this association may, and frequently does obtain. Thus, one of the most powerful known sources of heat is produced by burning a jet of mixed oxygen and hydrogen gases in the necessary proportions to constitute water; yet this combustion yields but very little light.

Now, if, for the purpose of generalising, we examine into the qualities of highly luminous flames, we shall find the luminosity to be dependent on the presence of incandescent solid matter—the illuminating power of incandescent gases being very inconsiderable. The high luminosity of phosphorus when burned in oxygen or the atmospheric air depends on the formation of phosphoric acid as the result of combustion—a white flocculent substance which you saw diffuse itself through the vessel—become attached to the glass, and to disappear only when it touched the surface of the water. Bright even to overpowering as the combustion of phosphorus in oxygen gas is at first, yet if consecutive portions could be burned in the same vessel without removing the crust of deposited phosphoric acid, the light developed would be all in vain so far as might relate to our observing it. The crust of deposited phosphoric acid would have collected round about, and, as a solid wall, would have obstructed our gases. And supposing phosphorus insead of carbon to have been our common agent of heat and light— supposing phosphoric acid to have been innoxious, too, so that it might have been taken into our lungs by respiration—supposing it, in short, to have been endowed with no noxious quality, but to have retained a harmless, passive, solid existence;—let us now see to what this would have led. Why, every source of common heat and illumination would have soon grown dim, notwithstanding the powerful evolution of light; the solid result of combustion—the ashes, so to speak— would have fallen like a mantle on every earthly object; light could neither have emanated nor been seen; the economy of nature would have been embarrassed, clogged for want of agencies to remove the results of combustion away, and all living things would have died!

How beautiful then—how wonderful to contemplate, the harmonious provisions by which the Creator has conferred on the element carbon the properties of at once ministering to us both artificial heat and light!

Had the result of the combustion of carbon been a gas only—a gas in every phase of its development—then we could have had but little amount of illumination. Had the result of its combustion been a solid—a permament solid—then the world would have been buried in its own ashes. It was necessary then, in order that the scheme of illumination and combustion should be complete—it was necessary for carbon to be so constituted that it should appear whilst in the act of combustion under two consecutive phases; that it should be a solid whilst evolving its light and heat, but immediately afterwards a gas. And are not these the very conditions manifested by carbon? Do we not see them manifested in the burning of a charcoal fire? Is not the mass all glowing one minute—the next dissipated into air? All this has been provided for—wonderfully, beneficently arranged. Carbon possesses every quality to render it adapted to its intended uses; not one property, however seemingly unimportant, could be added or taken away without destroying the whole harmonious scheme of nature—devised with such wisdom, maintained with such care.

This beautiful adaptation of carbon to our wants—the Protean-like quality which renders it capable of assuming the solid form one instant, when light and heat are required—the gaseous state next, when it has fulfilled its appointed functions and must hasten away—is in no instance more beautifully shown than in the combustion of a common candle. Yes, even a candle presents to the reflective and observant mind a beautiful field of research and admiration; and some of the most beneficent adaptations of carbon may be observed by merely holding strips of paper or cards transversely across a candle flame, as I do now. You will observe that, in intercepting the flame far down near the wick, I obtain deposited on the card a slightly carbonaceous ring; if I intercept the flame higher up, however, the amount of deposited carbon is more considerable; and now raising the card still higher the amount of carbon deposited is less again. Hence, we see even by the result of this simple experiment that the amount of carbon in a separate state is not everywhere equal throughout the flame, being deficient within the area of the faintly illuminated halo just around the wick, deficient again towards the summit of the flame, but attaining its maximum about half way up in that portion from which the maximum light is given forth. Still more instructive is it, however, to vary the experiment by substituting a syphon-like glass tube for the diaphragm of card or paper. The operation of this contrivance is as follows. Whatever gaseous or suspended matter enters the long leg of the syphon, is necessarily carried on by the draught along the tube, and made to emerge through the end of the shorter leg; and now, by making this shorter leg to end in a flask, we may abstract, decant, or lead away such volatile gaseous or suspended matter as the burning candle flame produces. Watch then the effect. If I lower the mouth of the long leg of the syphon down the faint halo surrounding the wick, the result decanted away is a white volatile matter quite free from carbon in its separate or simple form; and then you see this volatile matter deposits, sinks, and constitutes a layer in the flask. I now raise the end of the syphon into the luminous body of the flame—when observe once more the effect. No longer a white vapour pours over, but carbon body, into which the vapour has been changed, and which by becoming red-hot, incandescent, diffuses



its light. By raising up the end of the syphon still further up into that part of the flame where combustion is about to terminate, the amount of carbon drawn off is still less, until farther up it disappears altogether, having become changed by combustion into carbonic acid gas. This simple experiment then teaches us not only the beautiful adaptation of carbon to its end, as an illuminate and heating agent, but it satisfies us there is a consecutive where there would appear on casual observation a simultaneous decomposition. The volatile matter raised by combustion from the tallow of a candle is a vapour composed of carbon and hydrogen; and our experiment teaches us that the forces which hold these elements together are so nicely balanced that the hydrogen is made to combine first, the carbon afterwards.

In this case atmospheric oxygen being the supporting medium of combustion, both hydrogen and carbon are consumed in the end;—and here, too, is a beautiful instance of wise adaptation. Had not the balance of combining power between oxygen and carbon and hydrogen been just what it is, the precise result which we have seen, and which is so necessary to render combustion useful to our wants, could not have taken place. Suppose, for instance, oxygen, instead of having been endowed with combining powers as we find it, had been created with a strongly preponderating tendency of combination towards hydrogen, what then would have taken place? Why you shall see. In this tall jar I have a mixture of olefiant gas (a compound of carbon with hydrogen) and chlorine. I set fire to the mixture, and now observe the curious result. A flame rushes through the jar, union of chlorine with hydrogen takes place, and carbon is bodily deposited. This is the result which would have happened in the course of our most ordinary forms of combustion, had the combining tendency of oxygen with carbon been diminished. How beautifully then, how wonderfully, how beneficently have all these complex forces been arranged—combining together in harmony, never clashing with each other, tranquilly exercising their powers, and displaying in useful manifestations the functions imparted to them by the Creator!

The conditions involved in this experiment, of igniting potassium in air or oxygen, are sufficiently analogous in their relations to those which would have existed had the result of combustion of charcoal been non-volatile, to admit of our comparing the two. By heating potassium in atmospheric air potash is generated, which, not being volatile—soluble, thus to speak, in the air—lingers behind, crusts the potassium, and prevents that free access of oxygen indispensable to the process of combustion. Potash, however, is soluble in water; therefore, when I throw potassium into this fluid, combustion readily ensues, and is kept up until the potassium totally disappears, its crust of potash being removed as soon as formed. In this case the fluid water stands, with regard to potassium, in a parallel relation with the atmosphere as regards carbon—the ordinary agent of combustion in fireplaces and furnaces.

The peculiar influence of air upon ignited carbon in causing it to assume the condition of a gas may be conveniently illustrated by dipping a slip of paper into a solution of borax or alum, drying and igniting it. Under these circumstances, the air no longer being able to come in contact with the carbon of the paper on account of the varnish which forms over it as a crust, only the volatile portions of the paper are dissipated, carbon remaining unaffected. Hence, from a contemplation of this simple experiment, may be learned the function of atmospheric oxygen on carbon undergoing the combustive process.

And thus we have seen that the natural condition of burned carbon is the oxidised gaseous combination, carbonic acid: this the end of the combustive agency—this for carbon is the position of rest. By virtue of its gaseous quality it is enabled to escape; to be dissipated into the atmosphere, therein to float until taken up into new combinations and reduced into carbon again. Carbon we have seen to be naturally fixed when pure—to withstand the strongest heats we have in our power to command without volatilisation: fixity—non-volatility is its natural state, its most remarkable attribute. The reverse of this is the natural condition, is the prominent attribute of carbonic acid, and on this depends the due performance of many natural operations. Nevertheless, we have it in our power, by proper treatment, to change carbonic acid into a liquid and even into a solid by the application of certain means, thus proving that the gaseous condition is not immutably imparted to it, but is only a resultant of the nicely-balanced conditions under which it exists in nature.

Brilliant as are the phenomena of combustion—most interesting by their display of finely-balanced powers, and the all-wise adaptation of means to an end—most useful in ministering to our daily wants, and as forming the basis of so many civilising arts—there is another function in which carbon plays a part still more nearly interesting to us, as being a necessary concomitant of our existence—a function without the due performance of which there could be neither animal nor vegetable life—the function of respiration.

AMOUNT OF CARBON EVOLVED IN 24 HOURS—BY

A man	13¾oz. carbon
A milch-cow	70 ,,
A horse	79 ,,

This carbonic acid, which has long been reputed so violent a poison—and which, indeed, when existing beyond a certain ratio in the atmosphere, is incompatible with the existence of life—becomes, nevertheless, specially adapted, in virtue of its non-caustic, non-irritating qualities, to bathe unharmed the delicate tissues of the lungs, from the depths of which it is continually given forth. Had it been a caustic, irritating body, it is easy to recognise how totally unadapted it would have been to the performance of its designed functions in reference to those delicate organs. The physical operations of life may, in the aggregate, be assimilated to a slow process of combustion, the most striking results of which are the elimination of carbon and the production of heat. In this way an adult human being evolves daily from the lungs no less than thirteen and three-quarter ounces of carbon, a horse seventy-nine ounces, and a milch-cow seventy. Nor are these results to be regarded as extremes, but the average results of many experiments.

Although no provision has been made for the experiment in this lecture, any sketch of the points of carbonic acid would be incomplete were I to omit mentioning the beautiful discovery made by M. Thilorier of its conversion into a solid; an experiment not only curious in itself, but bearing a wide relation to other chemical substances—throwing great light upon the laws determining the cohesive state of substances generally. Previously to the investigations of M. Thilorier, carbonic acid, like many other gases, had been condensed into the liquid state by the pressure of its own elasticity, but this gentleman reduced this liquid carbonic acid to a solid by promoting its rapid evaporation, during which, heat is so rapidly given off from one portion of the liquid carbonic acid, that the remaining portion solidifies into a state something resembling snow.

This solid carbonic acid, although it may be touched with impunity, and does not ever feel very cold, on account of its bad conducting power for heat, or probably because of the continual evolution of gaseous acid which tends to prevent contact, yet, when mixed with sulphuric ether into a magma, furnishes us with a means of producing a temperature of no less than 166 degrees of Fahrenheit's thermometer below zero,—whereas the boiling point of water is only 212 above zero, or 180 degrees above its freezing point.

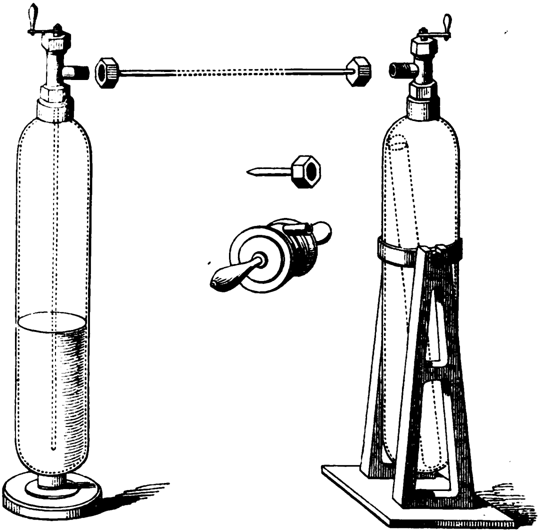
COMPARATIVE VIEW OF THERMOMETRIC DEGREES.

Centigrade.		Fahrenheit.	
100°	Water boils	212°	180°
0°	Water freezes	32°	
17° 7		0°	198°
40°	Mercury freezes	40°	
81° 6	Carbonic acid boils	115°	
50° 6	Carbonic acid freezes	70°	
100°	Lowest temperature	166°	

[The liquefication of carbonic acid was first accomplished by Mr. Faraday, who proceeded as follows:—A strong tube, of about one-fourth of an inch in diameter and eight inches long, being bent at about two inches from its end to an obtuse angle and sealed at the shorter end, sulphuric acid was poured in through a small funnel so as not to soil the larger leg, which was then loosely filled with fragments of carbonate of ammonia, and also hermetically sealed; the acid was then made to run upon the salt, and the evolved carbonic acid gradually appeared in the liquid form.

The compressing force employed in this operation is that of the elasticity of the gas itself. Subsequently this same principle has been adopted by M. Thilorier in the preparation of liquid carbonic acid on a very large scale, preparatory to the conversion of a portion of it into a solid form.

M. Thilorier, instead of one glass tube serving the purpose of generator and condenser, employs two cylindrical vessels, each of wrought iron, and each sufficiently strong to withstand a pressure of 4,000 lbs. on the square inch. One of these vessels serves as generator, the other as receiver.



The generator is furnished with an axis, and is mounted on an iron frame, so that it may revolve in a vertical plane. The receiver is supplied with a tube which goes nearly to its bottom.

Into the generator hangs a metal bucket, which admits of being filled with oil of vitriol, and the use of which will be apparent by and by. The vessel is put in action by charging the generator with a solution of bicarbonate of soda, and the bucket with sulphuric acid. The screw of the generator is now firmly closed, and the vessel attached to the condenser. The junction being well secured, the generator is now revolved on its vertical plane, when the oil of vitriol escaping comes into contact with the bicarbonate of soda and causes its decomposition. The progress of the operation will be evident. Carbonic acid passing over into the condenser, which is kept cool, becomes condensed into a fluid, which can be made to issue from the condenser in a continuous jet through the tube already mentioned as passing nearly to the bottom of the latter vessel. No sooner does the jet escape into the air than one portion immediately assumes the solid condition, in consequence of intense cold developed by evaporation of the other portion, and may readily be collected in the form of snow.]

We now arrive at the point of regarding carbonic acid as a chemical agent exercising certain powers; and we have to determine some measure of the intensity of these powers. In conducting this investigation we connot fail to be struck with the insufficiency of certain recognised experiments to convey adequate ideas of the subjects to which they refer. Carbonic acid is usually spoken of as a weak acid, and in its more common manifestations we may, without violence to language, call it so. Scarcely does it redden litmus paper, as we have seen, and so unstable are its combinations with bases that it is liberated from them, in the form of gas, by almost any other acid. But look at its combining equivalent, and observe that twenty-two parts by weight of this acid are capable of exercising a proportional combining or satisfying power, with no less than forty parts of sulphuric acid. Clearly, then, carbonic acid, when viewed in relation with this characteristic, cannot be designated as weak.

As a combining agent, satisfying the attraction of affinity and generating compounds, carbonic acid has a claim to be regarded as strong rather than weak; the only characteristics of weakness being its freedom from corrosive action, and its easy displacement. And now, looking at the numerous and varied functions of carbonic acid in the animal economy—looking at the important part it plays in the function of respiration—at the vast quantities of it in the simple and combined state, which pervade the systems of animated beings, let us foreshadow to ourselves the consequences that would have resulted had it been, like some acids, a corrosive body. If, by some revolution of existing laws, this quality could be imparted to carbonic acid, its relations would have been all disturbed—its harmony with existing functions marred—its application to the various relations of organic life rendered impossible.

Although carbon with oxygen yields compounds—carbonic oxide, and carbonic acid—which, on account of their prevalence in nature, their formation as the result of many common operations, must strikingly arrest our attention, yet there are others of especial interest to the chemist. Of this kind is a bicarburet of nitrogen, termed cyanogen, from the circumstance of its entering into the composition of Prussian blue: and here again we have one of those extraordinary examples of the indirect manner in which certain compositions are effected, no less than of the wonderful change of properties which results. Carbonic acid, although poisonous under certain circumstances, we have yet seen to be concerned in the ever-occurring function of respiration, bathing unharmed the air-cells of the lungs, remaining in contact with the most delicate tissues, yet producing no evil result: nitrogen, too, is endowed with a similar negative quality, this element constituting, as we have seen, no less than four-fifths of our atmosphere, which we breathe almost unconsciously without intermission from our birth to our death. Yet such is the strange effect of combination, that nitrogen, when united with carbon in the ratio of fourteen parts by weight to twelve, gives rise to a peculiar gaseous substance termed cyanogen, which if breathed only in small quantities proves fatal at once, and which by union with hydrogen constitutes that terrible—most terrible perhaps—of all poisons, hydrocyanic, or prussic acid. Cyanogen cannot be prepared, at least not readily and unequivocally, by the direct combination of its two elements, but is usually developed from its combination either with mercury or with silver. Its odour is that of peach-blossoms, and when burned it evolves a peculiar rose-coloured flame, which is very distinctive of this gas. Cyanogen, although a compound (bi-carburet of nitrogen), nevertheless unites with elements just as though it were a simple body, and this is one of its peculiarities. Thus with hydrogen it forms hydrocyanic acid, with oxygen cyanic acid, and repeats this combining tendency throughout the whole range of its compounds.

How beautiful a subject of contemplation is furnished us in the calm and tranquil exercise of nature's laws, which a study of natural phenomena discloses! The world with its ponderable constituents, dead and living, is made up of natural elements, endowed with nicely-balanced affections, attractions, or forces. Elements the most diverse—of tendencies the most opposed—of powers the most varied—some so inert that, to a casual observer, they would seem to count for nothing in the grand resultant of forces: some, on the other hand, endowed with qualities so violent that they would seem to threaten the stability of creation; yet, when scrutinised more narrowly, and examined with relation to the parts they are destined to fulfil, all are found to be accordant with one great scheme of harmonious adaptation. The powers of not one element could be modified without destroying at once the balance of harmonies, and involving in one ruin the economy of the world!

Look at the shells of these sea mollusca: nearly one-half of their total weight is carbonic acid. Gradually it has been collected from the surrounding medium—has pervaded the systems of these delicate creatures—has circulated in their fluids—has combined with lime, and finally been deposited by their mantles in the form of a shell. Had carbonic acid been corrosive, this could not have been. Carbonic acid would have, in that case, become totally unadapted to the performance of its destined end.

And now, in bringing to its conclusion this imperfect course, I have to thank my hearers for the patience with which they have listened to me,—I have to thank his Royal Highness for the condescension shown in his visit this day. During these lectures the passing thought has often occurred that I must be bringing matters before the notice of my audience that must have been foregone knowledge, to most, if not to all. I did not set out with the intention of making these lectures a medium of systematic exposition; still less did I intend them to embrace within their scope the minute chemical relations of the non-metallic elements. I desired only to regard these elements under their more prominent aspects—to glance at their broader similarities and distinctions,—to ponder over their harmonious adaptations, each to its appointed end. I desired to awaken in your minds a contemplation of those wonderful adaptations by which the elements are rendered subservient to purposes designed; to direct your attention to certain qualities of these non-metallic elements which cease to surprise from their very commonness and universality; and, lastly, to deduce from this a further evidence of the beneficence, power, majesty, and wisdom of the Eternal Disposer of all!

In conclusion, let me remark that the word element is only to be accepted in a provisional sense. Chemists are not without hope—a hope that we trust is not irrational—of being enabled to effect changes on some of these so-called elementary forms. The phenomena of allotropism seem to afford rational ground for this hope, and thus we are unconsciously brought back into tracks of thought and action having some similitude to the doctrines of alchemy:—similar, though not identical; not the transmutation of base metals into gold, but transmutation, nevertheless, of a certain kind.

In pursuing this field of speculation there is reason to believe we should derive much information as to the intimate nature of these non-metallic elements, if we could succeed in obtaining hydrogen and nitrogen in the liquid or solid form. Many gases have been liquefied; one, carbonic acid gas, has been solidified; but hydrogen and nitrogen have resisted all our efforts of this kind. Hydrogen, in many of its relations, acts as though it were a metal; could it be obtained in a liquid or solid condition, the doubt might be settled. This great problem, however, has yet to be solved; nor should we look with hopelessness on this solution, when we reflect with wonder—and, as I do, almost with fear and trembling, on the powers of investigating the hidden qualities of these elements—of questioning them, making them disclose their secrets and tell their tales—given by the Almighty to man!

THE END.

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